19970205 030

Independent Verification and Validation of the Hazardous Material Cost Trade-off Analysis Tool Developed by the Human Systems Center at Brooks Air Force Base

THESIS

Thomas S. Choi, Capt, USAF

AFIT/GEE/ENS/96D-01

DTIC QUALITY INSPECTED 3

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GEE/ENS/96D-01

Independent Verification and Validation of the Hazardous Material Cost Trade-off Analysis Tool Developed by the Human Systems Center at Brooks Air Force Base

THESIS

Thomas S. Choi, Capt, USAF

AFIT/GEE/ENS/96D-01

Views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government

THESIS APPROVAL

NAME: Thomas S. Choi, Captain, USAF **CLASS:** GEE-96D

THESIS TITLE: Independent Verification and Validation of the HAZMAT CTAT Developed by the Human Systems Center at Brooks AFB

DEFENSE DATE: 18 November 1996

COMMITTEE:	**NAME/TITLE/DEPARTMENT**	**SIGNATURE**
Advisor	Jack M. Kloeber Jr., LTC, USA Assistant Professor of Operations Research Department of Operational Sciences	Jack M Kloeber
Reader	W. Brent Nixon, Maj, USAF Assistant Professor of Department of Engineering and Evironmental Management	[illegible]
Reader	James Aldrich, Maj, USAF Assistant Professor of Department of Engineering and Evironmental Management	J Aldrich

AFIT/GEE/ENS/96D-01

Independent Verification and Validation of the Hazardous Material Cost Trade-off Analysis Tool Developed by the Human Systems Center at Brooks Air Force Base

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Engineering and Environmental Management

Thomas S. Choi, Capt, USAF

December, 1996

Acknowledgments

I would like to acknowledge and thank my thesis advisor, Lieutenant Colonel Jack Kloeber for his support and direction throughout the thesis process. Without his leadership and guidance, this thesis would have been a much more difficult task. I would also like to thank my committee members, Major James Aldrich and Major Brent Nixon, for their support and suggestions during the thesis effort.

My sincere gratitude to the employees of the McDonnell Douglas C-17 program. They were extremely helpful and gracious during the data collection effort. I would also like to thank Dr. John Long of the Analytical Sciences Corporation for his assistance during the thesis effort.

Finally, I would like to thank my wife, Susan, for her understanding and support throughout the thesis. Without her, this thesis would not have been possible.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE PAGE

LIST OF TABLES

TABLE PAGE

ABSTRACT

The Air Force realizes that the life cycle cost (LCC) associated with hazardous materials is a significant cost in the acquisition major weapon systems. In trying to mitigate the growth of environmental LCC for future weapon systems, the Air Force has developed a tool called the Hazardous Material Cost Trade-off Analysis Tool (HAZMAT CTAT). The HAZMAT CTAT estimates the LCC for weapon system hazardous materials, so that intelligent decisions can be made in the early stages of the acquisition process. The problem with implementing this program into the acquisition process is that an independent computer model evaluation has never been conducted on the HAZMAT CTAT program. This thesis contains a rigorous computer model evaluation of the HAZMAT CTAT. The evaluation includes a computer model verification study using Decision Program Language (DPL) to verify if the HAZMAT CTAT model and an operational validation study using C-17 historical data to test if the HAZMAT CTAT accurately predicts actual costs.

I. Introduction

Chapter Overview

This chapter describes the background for the thesis, the purpose of the study, problem statement, research objectives, research questions, and a short narrative on the proposed framework for the methodology.

Background

In the past decade, the Air Force Acquisition process "paradigm" has begun to embrace the realization that the life cycle cost (LCC) due to hazardous materials can be extremely high for major weapon systems. It is estimated that the environmental life cycle cost due to hazardous materials for the F-15 Eagle fighter aircraft program has been approximately $750 million (AFMC, 1992). Considering that the Air Force's inventory consists of numerous weapon systems, one can assume that the overall environmental LCC due to hazardous materials runs into the billions of dollars. Therefore, the integration of environmental requirements into the acquisition process has become a priority for the Department of Defense.

There are many factors which have fostered the growth of LCC analysis. Factors include rising inflation, cost growth experienced by many past weapons systems, the reduction in buying power, and continuing budget constraints (Blanchard, 1995:2). LCC centers around the idea that it is easiest to eliminate potential negative economic and environmental impacts at the beginning stages of the acquisition process.

Although the idea of environmental LCC is relatively new to the federal government, there have been many success stories in industry using LCC analysis for reducing hazardous materials. For example in 1987, a company named Rhone-Poulenc used life cycle costing to reduce waste in their salicylaldehyde process by 60,000 pounds while saving the company $250,000 annually with the cost of the process change being only $200,000 (Dorfman, 1992:407). Also in 1987, Dow Chemical's Pittsburg, California, plant employed life cycle costing by changing their process concerning wastewater from an acid gas adsorption system. This process change, which cost Dow $250,000, reduces wastes by 500 tons a month and saves $2.4 million a year (Dorfman, 1992:408). These examples indicate that the LCC approach is an effective way to manage the environmental issues of large programs and save considerable money.

The federal government is now trying to implement a hazardous material LCC approach in the acquisition of major weapon systems. The integration of environmental requirements in the earliest stages of the acquisition process centers around the concept of pollution prevention, which is the preferred solution in the DOD's environmental management hierarchy (DOD, 1989).

Weapon system pollution prevention is being implemented through the following programs:

1). Educating and training weapon system managers

2). Revising acquisition system policies

3). Providing better life-cycle costing tools

4). Revising military specifications and standards that require the use of hazardous chemicals

5.) Research and development of less harmful alternative materials (DOD, 1989).

One strategy currently being implemented in weapon system pollution prevention is the development of a LCC estimating tool which would allow decisions concerning the cost of chemicals to be made in the beginning of the acquisition process. Decisions made at the earliest stages are important because those decisions early in the acquisition process have the greatest effect on the life cycle cost of a weapon system. Figure 1.1 illustrates this point.

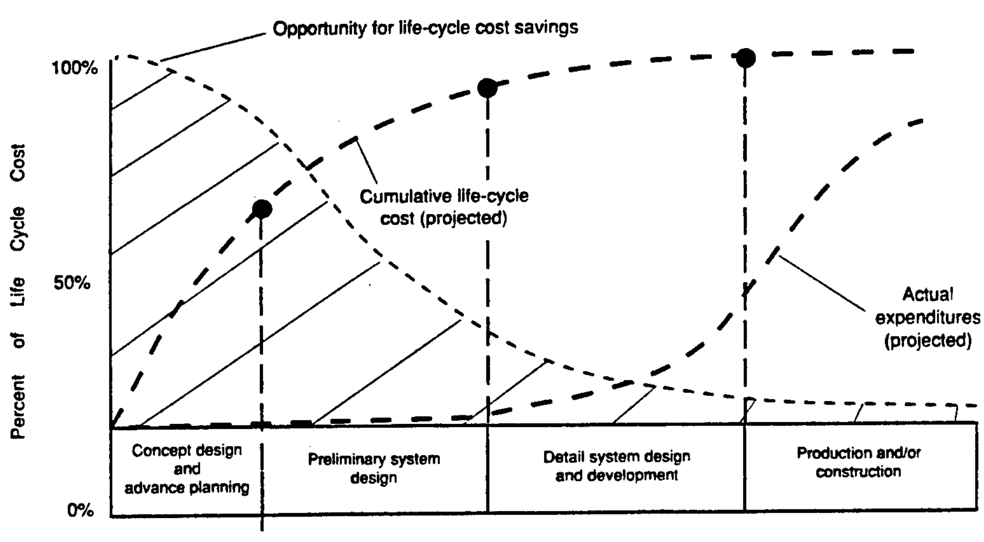


Figure 1.1 Cumulative life cycle cost curve (Blanchard, 1995:8)

This illustration conveys that more than half of the projected life cycle cost is committed at the end of the first stage even though little money is actually spent in the first stage. The LCC curve shows the potential adverse impact of making bad decisions in the beginning stages of the acquisition process. This is the main rationale for the current implementation of federal policies and directives requiring the analysis of environmental LCC at the beginning stages of the acquisition process. The federal government, the DOD, and the Air Force have passed numerous laws, initiatives, and directives requiring the use of environmental LCC estimating in the early stages of the acquisition process. These documents requiring LCC estimating fall into the following categories:

1). Executive Order (EO)

- EO 12873

2). Federal standards

- National Aerospace Standard (NAS) 411

3). DOD

- DODD 4210.15
- DODI 5000.2

4). Air Force

- Air Force Pollution Prevention Strategy
- Supplement to DODI 5000.2

Although these documents require an environmental LCC analysis in the acquisition of weapon systems, the Air Force acquisition program currently has no approved method of forecasting the environmental LCC of hazardous materials. The Human Systems Center (HSC) located at Brooks AFB developed the Hazardous Material Cost Trade-Off Analysis Tool (HAZMAT CTAT) environmental LCC analysis tool for the following reasons:

1). Environmental LCC can be predicted to enable appropriate chemical use changes to be made during the earliest stages of the acquisition process

2). HAZMAT CTAT would meet the requirements set forth by the Federal Government

The HAZMAT CTAT was identified as one of best LCC estimators for the acquisition process by the Communications Training Analysis Corporation (CTAC) in a report done on 22 Mar 1995 (CTAC, 1995). The CTAC report focused more on the superficial elements of the HAZMAT CTAT, such as the inclusion of certain cost categories, rather than the model's ability to predict real-world data. This report did not conduct a thorough independent computer model evaluation on the HAZMAT CTAT. The Human Systems Center at Brooks AFB wants a thorough independent computer model evaluation of the HAZMAT CTAT to establish the credibility of the HAZMAT CTAT or to identify deficiencies with the model.

In the development of any model, the model developers should assume that their model will be subjected to an independent assessment (Gass, 1980:711). This current deficiency creates a low level of confidence in the accuracy and applicability of the model to predict environmental LCC. An independent computer model evaluation is critical to the credibility of the HAZMAT CTAT.

Purpose of the Study

The purpose of this study is to conduct a rigorous computer model evaluation study on the Hazardous Material (HAZMAT) Cost Trade-off Analysis Tool (CTAT) developed by The Analytic Sciences Corporation (TASC) for the Human Systems Center located at Brooks Air Force Base.

Problem Statement

The Air Force has developed an environmental life cycle cost estimating tool, HAZMAT CTAT, in an effort to meet the requirements set forth by the federal government mandating the use of life cycle cost assessment for hazardous waste procurement in the acquisition of major weapon systems. Although the HAZMAT CTAT was developed in 1991, no rigorous computer model evaluation by an independent source has been done. It is the Air Force's intention to implement this model into the acquisition process, so a rigorous computer model evaluation study is imperative before the implementation occurs.

Research Objectives

The objective of this research is to conduct an evaluation of the HAZMAT CTAT developed by Brooks AFB.

This research has the following objectives:

1. Review all pertinent Federal, DOD, Air Force and AFMC regulations and directives which direct the acquisition process to incorporate environmental LCC and pollution prevention
2. Select and implement the most applicable computer model verification methodology
3. Select and implement the most applicable computer model validation methodology
4. Identify the most influential factors in the HAZMAT CTAT
5. Evaluate the usability of the HAZMAT CTAT into the weapon system acquisition process

Research Questions

1. Does the HAZMAT CTAT perform as intended by the developers of the model (verification)?
2. Does the output from the HAZMAT CTAT reasonably reflect the historical data from C-17 Globemaster III (validation)?
3. Which cost factors are the most influential in the HAZMAT CTAT (sensitivity analysis)?

4. If the output is not within the acceptable range, what are the causes?

Methodology Framework

The methodology framework for this thesis will be developed by reviewing several computer model evaluation methodologies currently in the literature. The methodology implemented should include sections that parallel the research questions stated above.

The evaluation methodology proposed by Robert Sargent is used and includes the following steps:

1. Computer model verification
2. Independent operational validation
3. Sensitivity Analysis
4. Conceptual model validation.

Verification is defined as the determination that a simulation performs as intended (Law and Kelton, 1982:333). Verification will be done using DPL software. The data used in the verification will come from the HAZMAT CTAT database, so that the data will be consistent for the verification.

Validation is defined as the determination of whether or not the conceptual model is an accurate representation of the system under study (Law and Kelton, 1982:334). Validation will be centered around comparing and analyzing the output from the HAZMAT CTAT model to historical data from the C-17 Globemaster III manufacturing process, McDonnell-Douglas production plant, Long Beach, California.

Computer Model Validity will determine if assumptions inherent in the HAZMAT CTAT are potential sources of error, if the differences in the validation data are not within the acceptable range, and will identify apparent deficiencies in the HAZMAT CTAT.

Sensitivity analysis will determine which factors are the most influential in the HAZMAT CTAT. DPL will be used for the sensitivity analysis. The results of the sensitivity analysis will be compared to the sensitivity performed by the model developer.

Outline

Chapter 2, Literature Review, summarizes the federal regulations and DOD directives which require environmental LCC estimating in the acquisition process. It presents past and present methodologies for verification and validation of models, and provides an overview of the LCC perspective.

Chapter 3, Methodology, provides, in detail, the approach used to verify and validate the HAZMAT CTAT and the method in which data was gathered.

Chapter 4, Analysis, provides the results and analysis from of the research. It will include results from verification and validation of the model and provide results from sensitivity and statistical analysis.

Chapter 5, Summary, presents conclusions reached from the analysis and recommendations for improvement of the model.

II. Literature Review

Chapter Overview

This chapter provides an overview and explanation of the documents mandating environmental LCC within the federal government and reviews perspective computer model evaluation methodologies current to literature. The first section highlights the directives and laws which require acquisition managers to perform hazardous material life cycle cost estimating prior to the procurement of weapon systems. This sections sets the framework for why the HAZMAT CTAT was developed for the acquisition of weapon systems. Documents requiring environmental life cycle cost analysis include Department of Defense and Air Force directives and initiatives, Executive Orders and Federal standards. The second section is a review of computer model evaluation methodologies. This section summarizes the methodologies are from Balci, Sargent, and Gass. The rationale for reviewing these computer model methodologies is that these authors are considered the leaders of the computer model evaluation methodology field (Banks, 1987). After the review, one of the computer model evaluation methodologies will be chosen to be implemented for this research.

Hazardous Material Life Cycle Cost Estimating Requirements

Hazardous material LCC analysis has become more important in recent years in the acquisition of weapon systems because past data has shown that the hazardous material LCC associated with weapon systems can run into the millions dollars throughout the life of a weapon system. The F-15 example on p.1-1 of Chapter One is a good example of this high environmental LCC. This trend is unacceptable for future acquisitions of major weapon systems due to tighter and tighter budgets constraints (Frabrycky, 1991:12).

Since most environmental impacts result from design decisions as shown in Figure 1.1 in Chapter One, the federal government has recently written and implemented many documents requiring that acquisition managers perform analysis on the environmental LCC of hazardous materials. Although the concern for environmental LCC is a recent paradigm shift within the federal government, this documents provide strong evidence that environmental LCC will be institutionalized in the way the acquisition managers procure weapon systems. Documents requiring hazardous material life cycle cost estimating fall into the following categories:

1. Executive Orders
2. Federal standards
3. Department of Defense
4. Air Force

Executive Orders

Executive Order 12873 of October 20, 1993 titled Federal Acquisition, Recycling and Waste Prevention directs federal agencies to implement acquisition programs aimed at encouraging new technologies and building markets for environmentally preferable and recycled products. Specifically in Section 410, Acquisition Planning, it states that in developing plans, drawings, work statements, specifications, or other products descriptions, agencies shall cover the following factors: elimination of virgin material requirements; use of recovered material; life cycle cost; recyclability; use of environmentally preferable materials and waste prevention (MITRE, 1995:A-9). The goal being that hazardous material life cycle cost be evaluated in the acquisition planning for all procurements.

Federal Standards

National Aerospace Standard (NAS) 411 was created by the Aerospace Industries Association in 1993 as an industry standard to be applied to United States government in the acquisition of systems, systems components, and associated support items and facilities. This standard applies to all acquisition phases and is designed to be contractually invoked for government procurements. The Hazardous Materials Management Program (HMMP), a contractor's plan created by NAS 411, influences system and product design process to eliminate, reduce, or minimize hazardous materials in all acquisition phases of a program. In Section 4.3.4, Trade-Off Analysis, the HMMP plan directs the following:

1. Analyze the potential costs associated with trading a hazardous material for a less hazardous material over the life cycle of the product subject to data available at the time of delivery

2. Document the trade-off analysis employed for selecting materials and processes (AIA, 1993)

In Section 4.3.4.1, Trade-Off Analysis Documentation and Recommendation, it states that documentation should contain justification for using a specific material or process and the reasons for rejecting other materials and process (AIA, 1993:4). The documentation shall also include known potential costs of particular hazardous materials in various phases of military use.

It is clear from these documents that hazardous material life cycle cost analysis is to be implemented in the acquisition of future weapon systems in an effort to lessen the financial and environmental impact of hazardous materials.

Department of Defense

Department of Defense Directive (DODD) 4210.15 titled Hazardous Material Pollution Prevention establishes policy, assign responsibilities and prescribe procedures for hazardous material pollution prevention. DODD 4210.15 states the DOD policy as the following as it pertains to hazardous materials:

"Hazardous material shall be selected, used, and managed over its life cycle so that the Department of Defense incurs the lowest cost required to protect human health and the environment (DOD, 1989)."

In Section 4 of DODD 4210.15, the heads of DOD components shall ensure that their organizations evaluate hazardous materials decisions by economic analysis techniques that match the magnitude of the decision being made, considering cost factors and intangible factors and to begin economic analysis of hazardous materials decisions at the earliest possible stage of the life cycle and modify analysis when better information becomes available (DOD, 1989). DODD 4210.15 is clear on the intention of implementing environmental life cycle estimating in the procurement of hazardous material. Department of Defense Instruction (DODI) 5000.2, Part 6, Section I titled Defense Acquisition Management Policies and Procedures: System Safety, Health Hazards, and Environmental Impact also provide strong, clear language on the policy concerning the procurement of hazardous materials.

DODI 5000.2 establishes policy and procedures for the basis of effectively integrating safety, health hazard, and environmental considerations into the system engineering process. In Section 3, Procedures, part 1 DODI 5000.2 states that the selection, use, and disposal of hazardous materials in the systems acquisition process will be managed over the system life cycle so that the Department of Defense incurs the lowest cost required to protect human health and the environment (DOD, 1995). In part 2 of this section it states that in selecting hazardous materials, the cost of acquiring, handling, using, and disposing of the material will be considered over the entire system life cycle and that these decisions should be supported by appropriate economic analysis (DOD, 1995). These two DOD documents mandate LCC analysis concerning hazardous materials.

<u>Air Force</u>

The Air Force Pollution Prevention Strategy from the Secretary of the Air Force, Sheila Widnall states:

> "Effectively promote pollution prevention by minimizing or eliminating the use of hazardous materials and the release of pollution into the environment.

Meet or exceed regulatory requirements through the use of education, training, and awareness programs, health-based risk assessments, acquisition practices, contract management, facilities management, energy conservation, and innovative pollution prevention technologies (SAF, 1995)."

The Air Force pollution prevention strategy consists of three major objectives. Objective two is to institutionalize pollution prevention into all phases of the weapon system life cycle. This provides the strongest language concerning environmental life cycle cost estimating. One sub-objective of objective two is to identify and/or develop tools (to include life cycle cost estimating) and milestones to support single managers with effective pollution prevention decisions (SAF, 1995). Another sub-objective states that procedures should be established to insure that all significant safety, occupational health, and environmental costs are included in the life-cycle cost estimates of Air Force acquisition programs to include analysis of direct and indirect costs.

Air Force supplement 1/DODI 5000.2 Part 6, Section I, titled System Safety, Health Hazards, and Environmental Impact also require the implementation of environmental life cycle cost estimating. In paragraph 3.c.(4)(a), it states that identification and evaluation of alternative materials processes that are less hazardous and more cost-effective over the life-cycle of the system shall be addressed in all phases of the acquisition process (AF supplement, 1995).

Computer Model Evaluation Methodologies

Model evaluations serve many purposes: education, model development, to aid decision-making, and documentation (Fossett, 1991:711). Although model evaluation serves many needs, there is little agreement on a standardized model evaluation methodology. One of the problems is the abundance of model evaluation methodologies. Landry states that there is no definite agreement as to what constitutes a valid model (Laundry, 1993:161). Law and Kelton also express the same sentiment stating that a review of the of the computer evaluation literature indicates that relatively little has been written on this subject (Law and Kelton, 1982:333). Although numerous computer evaluation methodologies exist in the field of operational science, I have chosen three methodologies to review for this section. These three authors were chosen because their methodologies were identified as the leaders in computer model evaluation methodologies (Banks, 1987). One of the three methodologies will be selected as the framework for the methodology for this research. As stated in Chapter One, the chosen computer model methodology must include independent verification and validation, sensitivity analysis, and validation analysis since these sections are required to answer the research questions. In this section, computer model evaluation methodologies from Balci, Sargent, and Gass are reviewed.

Osman Balci (1994)

In Balci's work, *Validation, verification, and testing techniques throughout the life cycle of the simulation study*, Balci implies that validation, verification, and testing

(VV&T) must be employed throughout the life cycle of the simulation study starting with problem formulation and ending with presentation of results. In fact, Balci states that the VV&T is not a phase or step, but a continuous activity throughout the entire life cycle (Balci, 1994:124). Figure 2.1 shows Balci's representation of the life cycle of a simulation study. The phases are shown by the shaded oval symbols. The dashed arrows describe the processes which relate the phases to each other. The solid arrows on Figure 2.1 refer to the credibility assessment stages. These credibility assessment stages define Balci's methodology for model validation.

The explanation of those areas are as follows:

1). Formulated Problem VV&T. The Formulated Problem VV&T is the first step in the validation process. This initial step deals with determining if the formulated problem contains the actual problem. Failure to formulate the actual problem results in Type III error (Balci, 1994:153).

2). Feasibility Assessment of Simulation. All the alternative techniques that can be used in solving the formulated problem should be identified. Among the qualified ones, the technique with the highest expected benefits/cost ratio should be elected.

3). System and Objectives Definition VV&T. This phase deals with determining the credibility of the system investigation process in which system characteristics are explored for consideration in system definition and modeling.

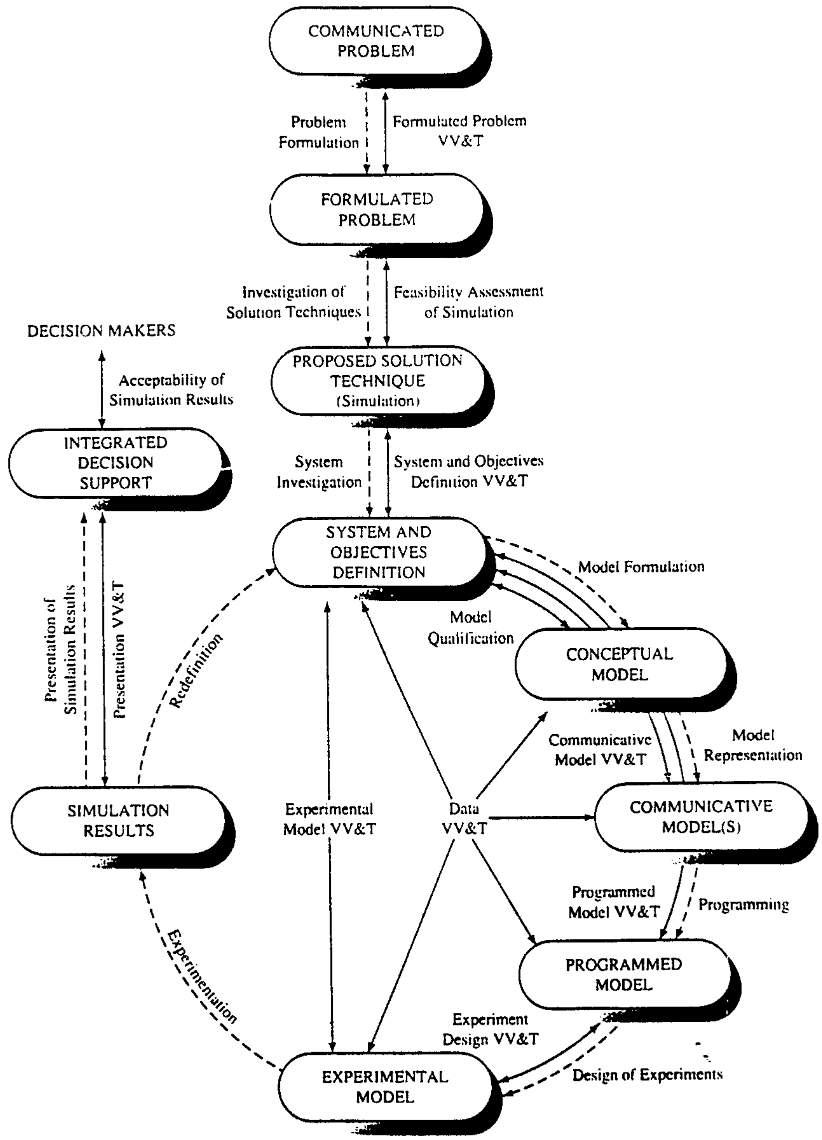


Figure 2.1 Balci's simulation study schematic (Balci, 1994:154)

This phase is used to identify the following six major system characteristics which tend to cause failures:

a) Change: How often and how much will the system change during the course of the simulation study?

b) Environment: Consists of all input variables that can significantly affect its state.

c) Counterintuitive behavior: Obvious solutions maybe ineffective in complex problems. It is essential that the study employ experts about the system to alleviate this problem.

d) Drift to low performance: Deterioration of its components over a period of time.

e) Interdependency: Complex systems have events that have many influences and that influence others.

f) Organization: Complex systems usually exist in some type of organized state.

4). Model Qualification. This phase deals with determining the credibility of the assumptions and that the conceptual model provides an adequate representation of the system under study. The conceptual model is defined as the model which is formulated in the mind of the modeler.

5). Communicative Model VV&T. Communicative model VV&T is the process of translating the conceptual model into a representative that can be communicated to other people and confirming the adequacy of the communicative model.

6). Programmed Model VV&T. This phase deal with assessing the process of translating the communicative model into a programmed model. A programmed model is an executable model.

7). Experimental Design VV&T. This phase deals with the process of designing experiments to test the computer model and to gather valid inferences from the output data. An experimental model is defined as a programmed model incorporating an executable description of operations presented in such a plan.

8). Data VV&T. This phase ensures that the data gathered for the validation study is accurate, complete, unbiased, and appropriate.

9). Experimental VV&T. This phase deals with determining that the experimental model has sufficient accuracy in representing the system as defined under the validation study objectives.

Balci's methodology consists of the nine phases mentioned above, but one must remember that this methodology is an iterative process and must be repeated until the validation study objectives are met or if the objectives become unattainable.

Robert Sargent (1994)

Sargent believed that a model should be developed for a specific purpose and that its validity be determined with respect to that purpose. Due to time and cost constraints, Sargent believed that it is irrational for most validation studies to produce absolute validity over its intended application, rather validation studies produce a certain level of confidence. Figure 2.2 depicts the complete simulation study methodology recommended by Sargent which consists of the following steps:

1). Conceptual model validity

2). Computerized model verification

3). Operational validity

4). Data validity.

Conceptual model validity is defined as determining that the theories and assumptions underlying the conceptual model are correct and that the model representation of the problem is reasonable. Another term for the conceptual model validation is face validation. In essence, this step is to determine if the appropriate logic, structure, mathematical and causal relationships are reasonable for its intended purpose.

Computer model verification is defined as ensuring that the computer programming and the implementation of the conceptual model is correct. This can be done with a separate programmed module or model to test the overall model and sub-models.

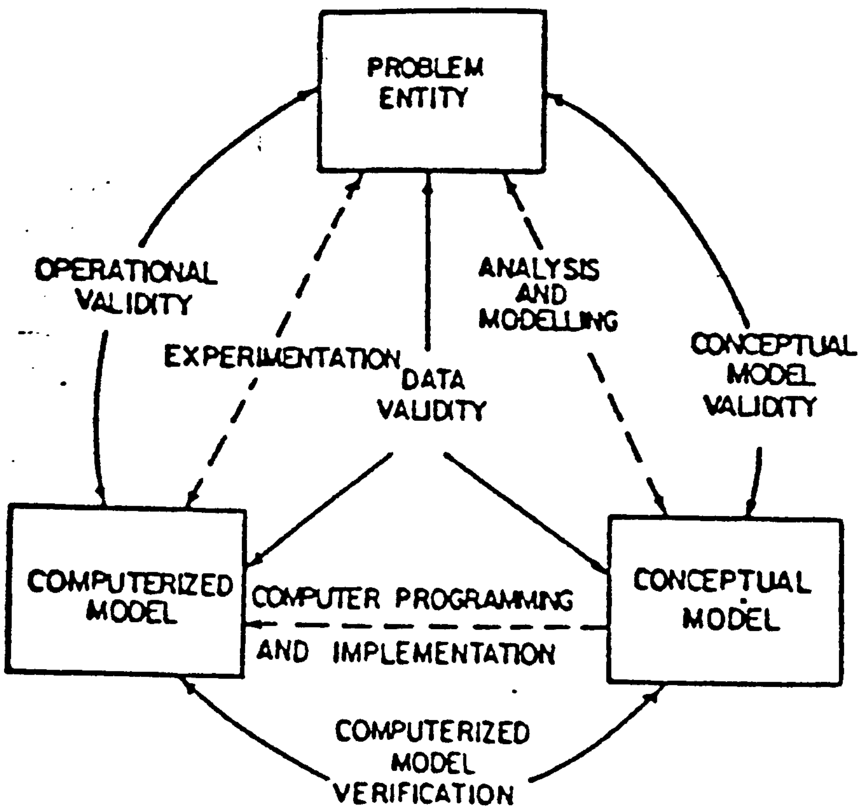


Figure 2.2 Sargent's simulation study methodology (Sargent, 1994:79)

Operational validity is defined as determining that the model's output behavior has sufficient accuracy for its intended purpose. This step is where most of the validation testing and evaluation takes place. Sargent presents the following three basic decision-making approaches in determining operational validity:

1). Independent verification and validation (IV&V)

2). Scoring model

3). Model development team.

The IV&V uses a third (independent) party to decide whether the model is valid. This approach removes the bias from the model developer and adds credibility to the validation study since someone outside the original model development team actually runs the validation study. This third party approach is usually used either when there is a large cost associated with the problem that the simulation model is being used for or when more acceptability and credibility for the simulation model is required. One major drawback from a third party analysis is the time and money associated with a third party validation. Due to this drawback, Sargent believes that a third party should be used primarily to evaluate the verification and validation study already conducted by the original model development team (Sargent, 1994:78).

The scoring model utilizes subjective scores or weights to conduct aspects of the validation study. These scores or weights are combined to determine category scores and these category scores are used to determine the level of validity of the model. Although the scoring model seems to be a simple method to validate a model, it has a few drawbacks including:

1. The method appears to be objective when it is really based on subjectivity. This method tends to be subjective because the scores (or weights) are determined using subjective methods.

2. The threshold score for passing is arbitrary.

3. A total passing score does not mean that the model is free of errors.

4. The scores may be mistaken for confidence or the scores may be used to compare models. Each validation score is dependent on the purpose of the simulation model and the validation study, so comparing the scores would be incorrect unless they are being used for the same purpose.

The model development team approach is the most common method used to make a determination that the model is valid (Sargent, 1994:78). This decision is based on a subjective decision based on the results and evaluations conducted as part of the model development process.

Data validity is defined as ensuring that the data necessary for model building, evaluation and testing, and conducting model experiments are adequate and correct. This step is important for all validation studies because data is necessary for validating the model and for performing experiments with the validated model.

<u>Saul Gass (1980)</u>

The computer model evaluation methodology presented by Gass is an abridged version of the guidelines recommended by the U.S. General Accounting Office (GAO) in a document entitled *Guidelines for Model Evaluation.* This guideline was developed by a model evaluation review group consisting of developers and user in business, industry, government, and academia (Gass, 1980:431). According to Gass, the evaluation of a model does not mean to second guess the intent or results of the model developers, rather it can assess the model and its results by using established set of criteria to accumulate evidence regarding the applicability and credibility of the model (Gass, 1980:432). The methodology for model evaluation presented by Gass was developed to be used for the models with the following characteristics:

1). Models that are developed to assist the policy analyst or decision-maker in selecting or evaluating various governmental policies

2). Mathematical models of a complex system that have been computerized

3). Large scale models

Since Gass' proposed methodology is general in nature, Gass emphasizes the following:

1). These criteria reflect concerns any decision-maker would wish to address before relying on the results

2). One must use a great deal of ingenuity, judgment and experience when adapting the criteria to a specific model. The set of criteria deemed necessary for model evaluation include the following:

1. Documentation
2. Validity: theoretical, data and operational
3. Computer model verification
4. Maintainability: updating and review
5. Usability

Documentation is defined as any written information concerning the model. Documentation is broken into two levels: descriptive and technical. Descriptive consists of general information such as underlying theory, assumptions and constraints. Technical consists of information that is sufficiently detailed to allow technical evaluation of the model. Documentation is vital to the evaluation because it ensures that the model can be understood, operated, and maintained in the future and it facilitates the ability for an independent evaluation of the model. Since the quality of the documentation cannot be assessed until complete review of the model, the evaluation process must start and end with documentation.

Validity is concerned with the model's ability of approximating reality. The validation step requires interaction between the model developer, the evaluator, and the users. There is no validation procedure appropriate for all models; the tasks must required by the model validation must be adjusted on the basis of the specific validation (Gass, 1980:435). Validity is viewed as being comprised of three sub-categories; theoretical, data, and operational.

Theoretical validity requires the evaluators to review theories underlying the model and if the transition from a theoretical model of reality to a mathematical model was made correctly. This process involves identifying and assessing the reasonableness of the most important assumptions made by the modeler in formulating the mathematical model.

Data validity is concerned with accuracy, completeness, and impartiality as well as the manner in which the model deals with the transformation of the original data.

Operational validity deals with assessing the importance upon the actual use of the model with errors and divergence. The result from the operational validity should include a list of computed parameters, decision variables, and to the extent that errors can occur.

Computer verification is to ensure that the model has the attributes which the developer programmed into it and it behaves as intended. Does the model "run as intended?" Verification should examine the following:

1). The mathematical and logical relationships are internally consistent

2). The mathematical and numerical results are correct and accurate

One should not expect complete verification for complex computer models (Gass, 1980:437).

Maintainability is concerned with how an acceptable model can be maintained during the life-cycle so that the model can continue to accurately represent the real world system. Two aspects of maintainability are review and updating. Review is concerned with regularly scheduled plan to review the accuracy of the model throughout its life cycle. Updating is concerned with developing a procedure in which to collect and analyze information to determine when changes need to be made in the model.

Usability is concerned with factors such as the availability of data, the understandability of the model's output, and the time and cost to run the model. The usability of the model is typically an important factor for the user.

III. Methodology

Chapter Overview

This chapter outlines the research approach used in the computer model evaluation of the HAZMAT CTAT model. The evaluation methodology used for this research was developed by reviewing the computer model evaluation methodologies discussed in Chapter Three. After reviewing the evaluation methodologies in Chapter Three, the methodology selected for this research is the methodology proposed by Robert Sargent. This chapter will discuss the rationale for selecting Sargent's methodology and apply the methodology to this research.

Rationale for Selecting Sargent's Methodology

There were two main criteria in selecting a methodology for this research. First, the selected methodology must be from an author that has developed unquestioned credibility in the field of computer model evaluation. Second, the overall framework of the methodology should parallel the overall goals of this research.

Sargent has developed unquestioned credibility in the field of computer model evaluation. In a survey of modeling processes, validation, and verification of computer models conducted by Jerry Banks of Georgia Institute of Technology, Robert Sargent was identified as one of those authors leading the field in computer model evaluation. Sargent's model contains all the common threads of a modeling process and gives the reader an excellent feel for the role of the computer model evaluation (Banks, 1987:15).

This provides evidence to the fact that Sargent is a leader in the field of computer model evaluation.

As stated in the introduction, the overall goal of this research centers around answering the research questions relevant to this research. The research questions are stated on p.1-8 in Chapter One. The one methodology that parallels the overall objective of this research is the methodology framework proposed by Sargent. The research questions required an independent validation and verification, sensitivity analysis, and validation analysis. The methodology proposed by Sargent includes computer model verification, operational validity, computer model validity, and data validity. These terms are defined on p.2-12 in Chapter Two. Sargent also believed in an independent or third party evaluation (Sargent, 1994:78). From reading those definitions and the research questions, the overall goal of the methodology and this research is very similar. The only step not consistent between the research questions and Sargent's methodology is data validity. Due to time constraints, one of the assumptions of this research is that the data collected is accurate for the purposes of this study. This assumption is discussed in Chapter Five under the section called Limitations of the Study. Although sensitivity analysis does not appear as a separate step in Sargent's methodology, it is include in the computer model verification step. Sargent states that factor screening to identify key factors should be done in the computer model verification (Sargent, 1994:81). For this purposes of this research, sensitivity analysis will done as separate step. Since Sargent's methodology meets both criteria, Sargent's methodology was selected for the framework of the research. The methodology section will consist of the following parts:

1. Computer Model Verification
2. Operational Validity
3. Sensitivity Analysis
4. Conceptual Model Validity

Computer Model Verification

Computer model verification is defined as ensuring that the implementation of the conceptual model is correct (Sargent, 1994:79). Sargent recommends that a method of verifying a computer model is by reprogramming critical components of the computer model to determine if the same results are obtained (Sargent, 1994:81). The use of another program module is recommended in the reprogramming of the critical parts of a computer model. The critical elements in the HAZMAT CTAT are the twelve cost categories that are used to calculate environmental cost for hazardous materials. Thus, the verification of the HAZMAT CTAT model must be centered on reprogramming the equations and factors in the twelve cost categories in the HAZMAT CTAT using a separate module and to determine if the same results are obtained. The separate module used for the verification is computer program called Decision Programming Language (DPL). This section will describe the procedure used to verify the HAZMAT CTAT model, the parameters used for the verification, the rationale for selecting DPL as the separate module, and a brief description of the DPL model.

Procedure for the Verification Study

1. Review the cost algorithms in the HAZMAT CTAT user guide

The twelve cost categories and the factors and algorithms that make up the categories are well defined in the HAZMAT CTAT user's guide. The objective of this step is to thoroughly study the HAZMAT CTAT user's guide to get a better understanding of the model and how the twelve cost categories and factors calculate environmental cost.

2. Run the HAZMAT CTAT for three hazardous materials for the three different scenarios listed in the Parameter Section

The three chemicals selected for the verification study will be done randomly. Three different cost scenarios will be done so that results of the verification will have more credibility. The rationale for selecting three different scenarios is on p.4-1.

3. Model the cost algorithms of the HAZMAT CTAT into the DPL program

DPL was chosen as the separate module program to model and verify the HAZMAT CTAT because of its sensitivity analysis capability. The rationale for selecting DPL is described on p.3-6 and a description and illustration of the influence diagram used for this study is on p.3-7.

4. Gather data for the three chemicals used in the HAZMAT CTAT input into the DPL model

The default factors used in the HAZMAT CTAT for the three hazardous materials will be used in the DPL model. The default factors are listed in the Appendix C.

5. Document problems during the reprogramming of the HAZMAT CTAT

There could be possible problems during the reprogramming of the HAZMAT CTAT into the DPL computer program. By documenting these problems, they can be identified to the original developers so that improvements can be made.

6. Verify that the outputs from both programs are identical

The outputs from both models using the exact algorithms must be exactly the same for the verification to be valid.

Verification Parameters

The parameters listed below reflect the parameter used in the HAZMAT CTAT model.

Verification #1	
Cost type: Total cost-per-year-per-subsystem	System name: Aircraft
System type: Cargo	Subsystem: Airframe
Chemicals: 1. Glass Fabrication Epoxy	Process: Acquisition (Manufacturing)
2. Glass Fabrication Phenolic	
3. Primer Zinc Chromate	

Verification #2	
Cost Type: Total Phase Cost	System name: Aircraft
System type: Cargo	Subsystem: Airframe
Number of Years: 4	Process: Acquisition (Manufacturing)
Interest: 10%	
Chemicals: 1. Glass Fabrication Epoxy	
2. Glass Fabrication Phenolic	
3. Primer Zinc Chromate	

Verification #3	
Cost Type: Total Phase Cost	System name: Aircraft
System type: Cargo	Subsystem: Airframe
Economic Life (Years): 5	Process: Operational and Support
Interest: 10%	Program Maintenance Schedule: 3
Chemicals: 1. Corrosive Preventive Compound	
2. Corrosive Resistant Coating	
3. Hydraulic Fluid	

Alternate Computer Program Consideration

Two computer programs were considered for use as the separate module in the verification of the cost algorithms in HAZMAT CTAT; Microsoft Excel and Decision Programming Language (DPL). Microsoft Excel software is a spreadsheet program which allows the user to perform numerous concurrent mathematical calculations. Excel could have been used for the verification of the HAZMAT CTAT. DPL is a decision analysis program which also allows the user to perform mathematical calculations as

Excel, but DPL has functions not inherent in Excel, such as user friendly sensitivity analysis on the algorithms used in the model and the inclusion of uncertainty. Since sensitivity analysis is an important aspect of this research, DPL was chosen to verify the cost algorithms in the HAZMAT CTAT.

Decision Analysis Programming (DPL)

Pictured below in Figure 3.1 is the general influence diagram used for the verification of the HAZMAT CTAT. Not shown in this general influence diagram are the factors and equations that go into the twelve cost categories. The complete influence diagram, with factors and equations, is illustrated in Appendix A. The influence diagram is a product of DPL software. Although three different influence diagrams were used in the verification, only the cost-per-year-per-subsystem is shown because the other two influence diagram have only minor differences from the one shown in Figure 3.1.

The other influence diagrams used for the verification are pictured in Appendix A. The main difference between the different influence diagrams is that Figure 3.1 only calculates the cost-per-year-subsystem and the other two calculate the environmental LCC based on an interest rate and the number of years. The purpose of this section is to briefly describe how an influence diagram functions.

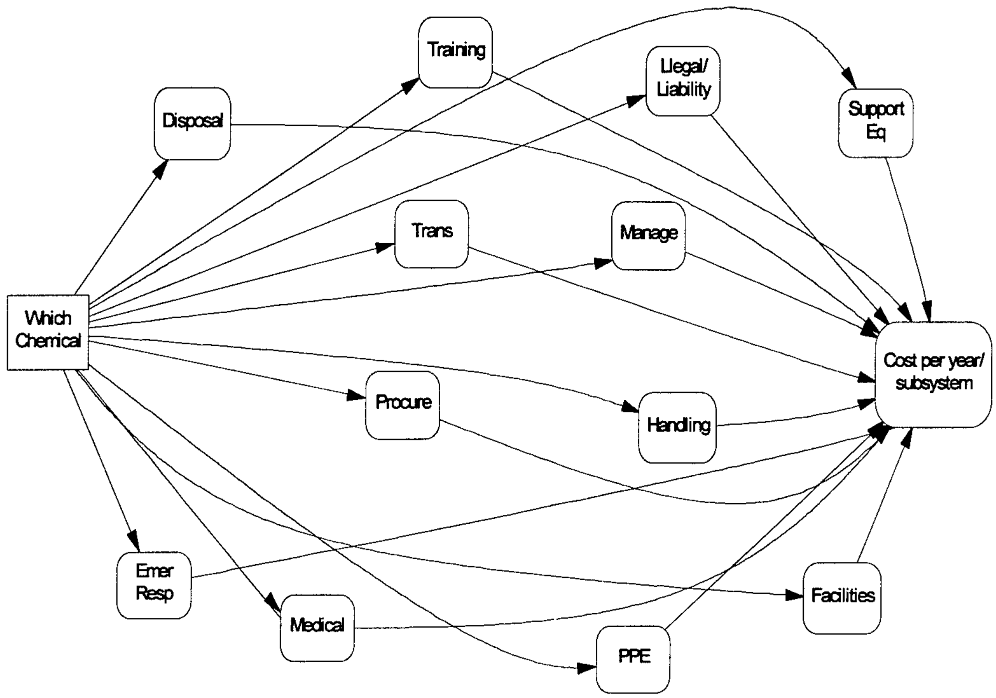


Figure 3. 1 Cost-per-year-per-subsystem influence diagram

An influence diagram provides a graphical representation of a decision problem (Clemen, 1994:34). The elements of an decision problem include the decisions, uncertainty of events, and the values of the outcomes. This influence diagram consists of only decisions to make and value of the outcomes. The rectangular node reflects a decision and a rounded rectangular node reflects a value node. The arrows define which nodes influence other nodes. In this particular influence diagram, the decision node influences the twelve cost categories and the twelve cost categories influence the total cost per year per subsystem. The decision node asks the question, "Which Chemical?" This question requires the user to input the chemicals for the environmental cost trade-off analysis. The rest of the nodes in the influence diagram are value nodes. Value nodes can be either a number or an algorithm. As mentioned before, all the value nodes are not pictured in Figure 3.1, but are shown in Appendix A. All the cost factors and algorithms in the HAZMAT CTAT are re-created through these value nodes. An illustration of how the nodes function to model the critical elements of the HAZMAT CTAT can be seen by looking a specific node in the influence diagram.

Pictured below in Figure 3.2 is the value node from the general influence diagram framework above titled Handling.

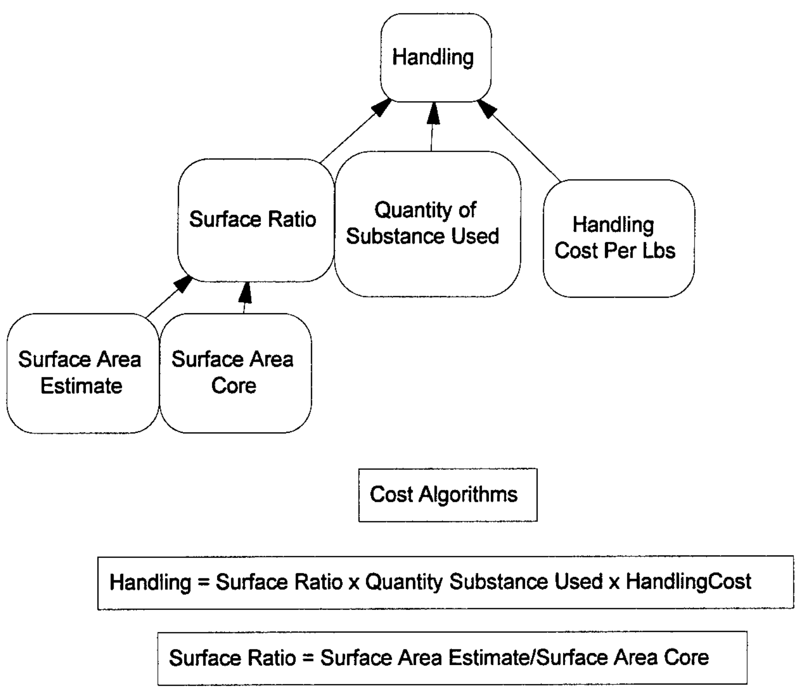


Figure 3.2 Handling cost representation

Included in the diagram are the factors that influence the Handling node and the algorithms that are associated with handling cost. The rest of the cost categories are shown in Appendix A. The twelve cost categories calculate the cost for that category and then perform the algorithm in the cost-per-year-per-subsystem value node shown in Figure 3.1. Cost-per-year-per-subsystem value node algorithm is a summation of the results of the calculations in the twelve cost categories. The final value calculated by the influence diagram should match the final output calculated by the HAZMAT CTAT for each chemical using the values from the different verification scenarios. An influence diagram illustrates the components of a complex program in an easy to understand manner.

Operational Validation

Operational validation is defined as determining that the model's output behavior has sufficient accuracy for its intended purpose over the domain of the model's intended applicability (Sargent, 1994:79). In essence, the operational validity is centered around the question, does the computer model output accurately represent real-world data. One of the recommended techniques suggested by Sargent for the evaluation of operational validity is historical data validation (Sargent, 1994:79). Sargent states that if historical data exists, it can be used to determine if the model behaves as the system does (Sargent, 1994:80) The use of historical data to assess the operational validity is a reasonable approach for this research. The one thing that Sargent fails to mention is a method of setting an objective measure to decide if a model is accurate or not. Saul Gass addresses this by stating that the decision-maker should set a criteria for a validation study (Gass, 1980:611). Basically, Gass believes that the measure of validation is in the eyes of the decision-maker for which the model is being developed for. This approach suggested by Gass seems appropriate for this study.

The decision-maker for this study is Ms. Betty West, the HAZMAT CTAT program manager, Human Systems Center at Brooks AFB. The criteria set by Betty West for the operational validity is that 80% of the HAZMAT CTAT output should be ± 25% of the MDA data. Thus, for the HAZMAT CTAT to pass the operational validity, seven of the eight chemicals must be ± 25%.

The historical data used to evaluate the operational validity of the HAZMAT CTAT will be gathered from the manufacturing process of the McDonnell-Douglas C-17 Globemaster III aircraft. The C-17 was chosen for the validation because it is the most recent major weapon system acquisition in the Air Force and there is environmental cost data available due to a current contract with MDA. This current contract with MDA analyzes the environmental LCC of hazardous materials in the manufacturing process. Due to this contract, it appeared that the C-17 would have the most abundant and relevant data concerning environmental LCC of hazardous materials.

The operational validation section will describe the procedure used for the operational validity and provide a brief overview of the output data analysis tools considered for this research. The procedure used for the operational validation is not a direct procedure suggested by Sargent, but it incorporates the fundamental technique in using historical data for the operation validation as suggested by Sargent. The output data analysis tools considered for this research are consistent with the tools recommended by Sargent.

Procedure for the Operational Validation

1. Gather data on 8 hazardous materials for environmental costs in the manufacturing process for C-17 aircraft from McDonnell Douglas (MDA)

Due to time constraints, data was available on only 8 hazardous materials. The hazardous materials for the task orders is listed below:

1. Task order #3: 1,1,1 Trichloroethane
2. Task order #4: Vapor degreaser
3. Task order #5: Seal adhesive
4. Task order #6: Penetrant Remover
5. Task order #7: Quik Freeze
6. Task order #8: Corrosion inhibiting sealant
7. Task order #9: Electrical contact cleaner
8. Task order #10: Chemical locking compound

2. Learn how McDonnell Douglas calculates environmental LCC and determine how real-world/historical data is collected for their calculations

A site visit occurred from 9 June-15 June 1996 to research the methodology behind MDA environmental LCC calculations. The purpose of the site visit was to get a better understanding of how MDA calculated environmental LCC for hazardous materials and to ensure that methodology behind their data gathering was credible. Informal interviews were conducted on MDA personnel who were the point of contacts for environmental LCC data to get a better understanding of the MDA environmental LCC process. Listed below are the names and titles of the people interviewed during the site visit.

-Mark Slusarz, Life Cycle Cost Analyst

-Ron Fornator, Senior Environmental Engineer

-Mark Pfotenhauer, Procurement/Supply

-Steve Gochnauer, Fire Services

-Larry Colshan, Facility Maintenance

-Ugen Thy Tran, Industrial Hygienist

-Tricia Hughes, Medical Office Assistant

-Lisa Arevalo, Registered Nurse

-Bob Hollenbeck, Director of Health, Safety, and Environmental

Along with interviews with the personnel, documents were reviewed to ensure that the data reported by these points of contacts were reasonable. For example, the Lisa Arevalo, a MDA nurse, was interviewed concerning the medical data used in the MDA model. Along with the interview, documents were reviewed to ensure that the number were credible.

3. Standardize the Cost Categories

This step is to ensure that the comparison of the environmental costs is fundamentally sound. Both models will be standardized so that only the common cost categories will be incorporated into the comparison of the environmental cost. The McDonnell-Douglas environmental cost calculation includes the following cost categories in their calculation:

1. Procurement
2. Handling
3. Training
4. Personal Protection Equipment
5. Medical
6. Disposal
7. Legal Liability

Only these categories will be used to compare the environmental cost for hazardous materials in the HAZMAT CTAT model since these are the only cost categories addressed by MDA in calculating the environmental cost for hazardous materials.

4. Produce Cost Estimates

The HAZMAT CTAT will be used to get total cost per year per subsystem for the manufacturing phase for the same hazardous materials as listed in step 1. The cost will be in 1996 dollars. Although default values in the database are used for most of the factors, some regional factors will incorporated into the HAZMAT CTAT to reflect California influences since the C-17 plant is located in Long Beach, California. The factors that will reflect California influences are as follows:

1. Average hourly wage
2. Training cost

The average hourly rate was gathered by using the Department of Labor's Bureau of Labor Statistics (BLS). I will use the BLS to get the average hourly wage for manufacturing in California. Since the BLS only shows yearly cost, I divided the yearly cost by 2080 hours to get the hourly rate. I then multiplied by 200% to reflect total burden costs as suggested by Wright-Patterson AFB financial management flight since the BLS statistics do not reflect total burden cost. Training cost was calculated by adding 100 percent to the hourly rate of a laborer. The assumption here is that the trainers will typically make more money than laborers.

5. Check for operational validity.

Data analysis tools used in determining the operational validity of the model will be consistent with the tools recommended by Sargent. The goal of the data analysis tools is to determine if costs for seven of the eight chemicals are ± 25% of the actual costs-a standard set by Ms. Betty West, the decision-maker. The secondary goal is to analyze the data to determine if the there are trend associated with the data.

Output Data Analysis Overview

The output data analysis tools recommended by Sargent falls into three categories: graphical comparison of the data, confidence intervals, and hypothesis testing (Sargent, 1994:82). For the purposes of this research, only graphical comparison of the data and hypothesis testing will used for this research (See Table 3.1).

Table 3.1 Data analysis tools

1. Percentage differences between outputs
2. Hypothesis testing
3. Trend analysis graphs

The two types of hypothesis testing considered for this study are:

1. One sample test
2. Two sample test
   a. Parametric
   b. Non-parametric

The one sample t test will be conducted on the percentage differences to determine if the evidence suggests that the null can be either rejected or not rejected. The one sided t test methodology is the following (Devore, 1995:322)

Null Hypothesis: H_o: $\mu = 0$

Alternate Hypothesis: H_a: $\mu > 0$

Test Statistic: $t^* = \dfrac{\text{Xbar} - 0}{S / \sqrt{N}}$

Rejection Region: $t^* \geq t_{\alpha, n-1}$

In the above methodology, μ is defined as the true mean of the percentage differences, Xbar is defined as the sample mean, S is defined as the sample standard deviation, and N is defined as the sample size. The underlying assumption in using the one sample t test is that the data is distributed normally. The Wilk-Shapiro test will be used to check the normality of the percentage differences. Since this is a one-tail test, the null is rejected if the calculated t* is greater than or equal to the theoretical t for a given alpha. Alpha for this test is discussed in p.3-20.

The two sample hypothesis will consider a parametric or non-parametric test. The two sample test will statistically test the differences between the MDA and HAZMAT CTAT data. This is not to be confused with percentage differences tested in the one sample t test. The two sample test will test the actual differences. The parametric test that will be considered is the paired t test because the paired t-test is a statistical tool to test the difference of two means. The use of the paired t test is predicated on meeting following list of underlying assumptions (Hatcher, 1994:209).

1. Level of measurement: The criterion variable should be assessed on an interval or ratio level of measurement and the predictor variable should be nominal level of measurement.

2. Paired observations: A given observation appearing in one condition must be paired in some meaningful way with a corresponding observation appearing in the other condition.

3. Independent observations: A given subjects score in one condition should not be affected by any other subject's score in either of the two categories.

4. Random sampling: Subjects contributing data should represent a random sample drawn from the sample population.

5. Normal distribution: The differences in paired scores should be distributed normally.

6. Homogeneity of variance: The population represented by the two categories should have equal variances.

The two sided paired t-test will use the following methodology (Devore, 1995:368):

Null Hypothesis: H_o: $\mu_d = 0$

Alternate Hypothesis: H_a: $\mu_d \neq 0$

Test Statistic: $t^* = \dfrac{\text{Dbar} - \Delta o}{S_D / \sqrt{N}}$

Rejection Region: $t^* \geq t_{\alpha/2,\, n-1}$ or $t^* \leq -t_{\alpha/2,\, n-1}$

In the above methodology, μ_d is defined as the difference between the two means. In this case that is the difference between the MDA cost and the HAZMAT CTAT output. Dbar is defined as the sample mean, S_D is defined as the sample standard deviation, and N is defined as the sample size. Since this is a two-tail test, the null is rejected if t* is greater than or equal to the positive t-statistic or if t* is less than or equal to the negative t-statistic for a given alpha. If the data for this study does not meet the six underlying assumptions relevant to the paired t test, an alternative test will be used. The alternative test is a non-parametric test called the Wilcoxon Signed-Rank test.

The Wilcoxon Signed-Rank test is a good alternative to the paired t test when the paired t test can not be used (Devore, 1995:637). The reason why the Wilcoxon Signed-Rank test can be used is because the requirements for using the Wilcoxon Signed-Rank test is less restrictive. The Wilcoxon Signed-Rank test requires that both data sets be continuous and symmetrical, but the differences do not need to be distributed normally as required by the paired t test (Devore, 1995:633). The assumption of symmetry will be checked using a box and whiskers plot. The two sided Wilcoxon Signed-Rank test methodology is as follows:

Null Hypothesis: H_o: $\mu = \mu_0$

Alternate Hypothesis: H_a: $\mu \neq \mu_0$

Test Statistic: $S_+ =$ the sum of the ranks associated with positive differences

Rejection Region: $S_+ \geq C1$ or $S_+ \leq C2$.

In the Wilcoxon Signed-Rank methodology, μ is defined as the mean of one distribution and μ_0 is defined as the mean of the other distribution. C1 is obtained from Appendix A.9 (Devore, 1995:713) and C2 is calculated by using the equation: N(N+1)/2-C1. Since this is a two-tail test, the null is rejected if S_+ is greater than or equal to C1 or if S_+ is less than or equal to C2.

When one performs a hypothesis test, two types of errors can be made. One of the errors is called Type 1 error. Type I error is when one rejects the null hypothesis when it is in fact true. Type I error is important because the probability of Type I error is equal to the level of alpha and is thus under the control of the experimenter. For this research, Ms.

Betty West is the decision-maker and thus controls the level of Type I error. The alpha set for the one-tail one sample t test is .1 and the alpha set for the two-tail two sample test is .20. This level chosen is significant because the alpha has a direct impact on the probability of rejecting the null. This is because the null is rejected when the calculated t, t^*, is greater than the theoretical t for a given alpha. As alpha becomes larger, the theoretical t becomes smaller, thus it is easier to reject the null. For this reason, a lower alpha is used in most hypothesis tests.

Conceptual Model Validity

Conceptual model validity is defined as determining that the theories and assumptions underlying the conceptual model are correct (Sargent, 1994:80). Sargent believed that the conceptual model validity tries to determine the reasonableness of the logic and assumptions made by the developers. This section will be consistent with Sargent's goal and will concentrate on identifying problems with the assumptions and theories that are the potential sources of differences in the validation study. This section will also identify possible fundamental deficiencies of the HAZMAT CTAT. Examples will be shown to support why the identified assumptions and theories are potential causes of the differences between the MDA and HAZMAT CTAT data. The goal of the section is to get further insight into the HAZMAT CTAT and identify concerns with the model or with the reporting and recording of the MDA data.

Sensitivity Analysis

Although the sensitivity analysis was recommended by Sargent in the computer verification phase, it was incorporate as an independent section in this research. Sargent believed that factor screening experiments should be conducted to identify the key factors of a model. This is the goal of the sensitivity analysis. Sensitivity analysis will be conducted using DPL to determine which factors are the most influential to the HAZMAT. Sensitivity analysis is performed by systematically changing values of the model input variables and parameters and observing the effect upon model behavior (Balci, 1994:140). In essence, the sensitivity analysis allows the analyst to get more insight into the model and to determine which variables and parameters are the most influential to a particular model.

Once the analysis is complete, the sensitivity analysis results using the verification model will be compared to the sensitivity analysis results shown in the HAZMAT CTAT user's guide.

Chapter IV. Analysis

Chapter Overview

This chapter presents the results from employing the methodology described in Chapter Three to verify the HAZMAT CTAT and to conduct an operational validation study. The validity of the conceptual model will be addressed and, finally, the results of the sensitivity analysis will be discussed.

Verification Results

Verification for this study was based on the method suggested by Sargent as discussed on p. 3-3. The critical elements of the HAZMAT CTAT were reprogrammed in a separate program to determine if the HAZMAT CTAT calculate as were intended by the developers of the model (Sargent, 1994:78). The entire HAZMAT CTAT model was implemented in a language called DPL. If the newly produced computer model produces numerical results matching the results from the HAZMAT CTAT, then the HAZMAT CTAT cost algorithms will have been verified.

For this verification study, three different scenarios with different verification parameters were chosen to verify the HAZMAT CTAT. The verification parameters used for this study are shown on p. 3-5 in Chapter Three. The rationale for verifying three different scenarios rather than just one is to increase the credibility of the results from the verification study. The HAZMAT CTAT consists of three phases: acquisition (manufacturing), operational and support (O&S), and disposal. For these three phases, there are two types of cost calculations: cost-per-year-per-subsystem and total phase cost. The number of combinations equals six scenarios. The reason four scenarios can account for six is that the cost-per-year-per-subsystem analysis is the same for each phase, thus if one cost-per-year-per-subsystem analysis is conducted it represents three scenarios (Long, 1996). For this verification, the disposal total phase analysis was excluded since analyzing three out of four possible scenarios was assumed to be sufficient for the purposes of this study.

There were several problems identified during the verification study that are errors in the HAZMAT CTAT User's Guide. These problems caused the PPE and Total Cost output from DPL, the verification software package, to vary from the HAZMAT CTAT PPE and Total Cost output. Table 4.1 shows the discrepancies between the DPL output and the HAZMAT CTAT output. The HAZMAT CTAT results are located in the left column and the DPL results are located in the right column.

The problems in the user's guide included typographical mistakes and missing mathematical symbols. The Equipment Cost Individual algorithm on p.74 of the User's Guide had a multiplication sign and an addition sign side by side. It was typographical error and only the addition sign should have been there (Long, 1996). The terms Air Environmental and Air Cost are mislabeled on p.84 of the User's Guide. The algorithm defining Air Cost is labeled as Air Environmental.

Table 4.1 Manufacturing cost-per-year-per-subsystem

	HAZMAT CTAT	DPL Model
Procurement		
Glass Fabrication Epoxy	$90	$90
Glass Fabrication Phenolic	$140	$140
Primer Zinc Chromate	$70	$70
Transportation		
Glass Fabrication Epoxy	$13	$13
Glass Fabrication Phenolic	$13	$13
Primer Zinc Chromate	$61	$61
Handling		
Glass Fabrication Epoxy	$27	$27
Glass Fabrication Phenolic	$27	$27
Primer Zinc Chromate	$128	$128
Management		
Glass Fabrication Epoxy	$10	$10
Glass Fabrication Phenolic	$10	$10
Primer Zinc Chromate	$47	$47
Training		
Glass Fabrication Epoxy	$2,267	$2,267
Glass Fabrication Phenolic	$2,267	$2,267
Primer Zinc Chromate	$2,267	$2,267
Legal/Liability		
Glass Fabrication Epoxy	$15	$15
Glass Fabrication Phenolic	$36	$36
Primer Zinc Chromate	$175	$175
Medical		
Glass Fabrication Epoxy	$35,484	$35,483
Glass Fabrication Phenolic	$35,484	$35,483
Primer Zinc Chromate	$35,484	$35,483
Facilities		
Glass Fabrication Epoxy	$9	$9
Glass Fabrication Phenolic	$9	$9
Primer Zinc Chromate	$41	$41
Support Equipment		
Glass Fabrication Epoxy	$0	$0
Glass Fabrication Phenolic	$0	$0
Primer Zinc Chromate	$1	$1
Emergency Response		
Glass Fabrication Epoxy	$0	$0
Glass Fabrication Phenolic	$0	$0
Primer Zinc Chromate	$0	$0
Disposal		
Glass Fabrication Epoxy	$0	$0
Glass Fabrication Phenolic	$1	$1
Primer Zinc Chromate	$29	$29
Personal Protection Eq		
Glass Fabrication Epoxy	$131,451	$47,415
Glass Fabrication Phenolic	$131,435	$47,399
Primer Zinc Chromate	$312,664	$102,574
Total Cost/Year/Subsystem		
Glass Fabrication Epoxy	$169,366	$85,330
Glass Fabrication Phenolic	$169,423	$85,387
Primer Zinc Chromate	$350,967	$140,877

These two errors however were not the major causes of the differences shown in Table 4.1. The error causing the majority of the discrepancies in Table 4.1 concerns a term called Time Lost. This term is part of the PPE algorithm. On p.74 of the User's Guide, the algorithm for the term Time Lost does not indicate that the Time Lost is actually a summation of all the Time Lost associated with the different pieces of PPE worn in that process. Since the summation sign is excluded in the User's Guide, it caused the PPE and Total Cost output from DPL to be significantly less than the HAZMAT CTAT PPE and Total Cost output. Once these corrections were identified and corrected in the DPL model, the results from the DPL model and the results from the HAZMAT CTAT model began to resemble each other. Tables 4.2-4.4 illustrates the output once the corrections were made. The numbers were rounded depending on the magnitude of the number. For example, if the output was $92.41, it was rounded to 90 or if the output was $2,456,456 the number was rounded $2,456,500. The results from each cost category are shown and then the total cost per year per subsystem is shown.

A comparison of the results from shown in Tables 4.2-4.4 illustrates that the verification of the HAZMAT CTAT using DPL as suggested by Sargent produce exactly the same numbers once the corrections were implemented. Thus, the HAZMAT CTAT does indeed use the formulas shown in the User's Guide. These results present strong evidence that the developers correctly implemented their model. The minor corrections to the User's guide should be made as already discussed.

Table 4.2 Manufacturing cost-per-year-per-subsystem

	HAZMAT CTAT	DPL Model
Procurement		
Glass Fabrication Epoxy	$90	$90
Glass Fabrication Phenolic	$140	$140
Primer Zinc Chromate	$70	$70
Transportation		
Glass Fabrication Epoxy	$13	$13
Glass Fabrication Phenolic	$13	$13
Primer Zinc Chromate	$60	$60
Handling		
Glass Fabrication Epoxy	$27	$27
Glass Fabrication Phenolic	$27	$27
Primer Zinc Chromate	$130	$130
Management		
Glass Fabrication Epoxy	$10	$10
Glass Fabrication Phenolic	$10	$10
Primer Zinc Chromate	$50	$50
Training		
Glass Fabrication Epoxy	$2,270	$2,270
Glass Fabrication Phenolic	$2,270	$2,270
Primer Zinc Chromate	$2,270	$2,270
Legal/Liability		
Glass Fabrication Epoxy	$15	$15
Glass Fabrication Phenolic	$40	$40
Primer Zinc Chromate	$180	$180
Medical		
Glass Fabrication Epoxy	$35,500	$35,500
Glass Fabrication Phenolic	$35,500	$35,500
Primer Zinc Chromate	$35,500	$35,500
Facilities		
Glass Fabrication Epoxy	$9	$9
Glass Fabrication Phenolic	$9	$9
Primer Zinc Chromate	$40	$40
Support Equipment		
Glass Fabrication Epoxy	$0	$0
Glass Fabrication Phenolic	$0	$0
Primer Zinc Chromate	$1	$1
Emergency Response		
Glass Fabrication Epoxy	$0	$0
Glass Fabrication Phenolic	$0	$0
Primer Zinc Chromate	$0	$0
Disposal		
Glass Fabrication Epoxy	$0	$0
Glass Fabrication Phenolic	$1	$1
Primer Zinc Chromate	$30	$30
Personal Protection Eq		
Glass Fabrication Epoxy	$131,400	$131,400
Glass Fabrication Phenolic	$131,400	$131,400
Primer Zinc Chromate	$312,700	$312,700
Total Cost/Year/Subsystem		
Glass Fabrication Epoxy	$169,400	$169,400
Glass Fabrication Phenolic	$169,400	$169,400
Primer Zinc Chromate	$351,000	$351,000

Table 4.3 Manufacturing total phase cost-per-subsystem

	HAZMAT CTAT	DPL Model
Procurement		
Glass Fabrication Epoxy	$2,840	$2,840
Glass Fabrication Phenolic	$4,420	$4,420
Primer Zinc Chromate	$2190	$2190
Transportation		
Glass Fabrication Epoxy	$400	$400
Glass Fabrication Phenolic	$400	$400
Primer Zinc Chromate	$1920	$1920
Handling		
Glass Fabrication Epoxy	$834	$834
Glass Fabrication Phenolic	$834	$834
Primer Zinc Chromate	$4,000	$4,000
Management		
Glass Fabrication Epoxy	$308	$308
Glass Fabrication Phenolic	$308	$308
Primer Zinc Chromate	$1480	$1480
Training		
Glass Fabrication Epoxy	$284,600	$284,600
Glass Fabrication Phenolic	$284,600	$284,600
Primer Zinc Chromate	$284,600	$284,600
Legal/Liability		
Glass Fabrication Epoxy	$460	$460
Glass Fabrication Phenolic	$1,140	$1,140
Primer Zinc Chromate	$5,490	$5,490
Medical		
Glass Fabrication Epoxy	$445,400	$445,400
Glass Fabrication Phenolic	$445,400	$445,400
Primer Zinc Chromate	$445,400	$445,400
Facilities		
Glass Fabrication Epoxy	$270	$270
Glass Fabrication Phenolic	$270	$270
Primer Zinc Chromate	$1,280	$1,280
Support Equipment		
Glass Fabrication Epoxy	$8	$8
Glass Fabrication Phenolic	$8	$8
Primer Zinc Chromate	$41	$41
Emergency Response		
Glass Fabrication Epoxy	$0	$0
Glass Fabrication Phenolic	$0	$0
Primer Zinc Chromate	$0	$0
Disposal		
Glass Fabrication Epoxy	$11	$11
Glass Fabrication Phenolic	$42	$42
Primer Zinc Chromate	$920	$920
Personal Protection Eq		
Glass Fabrication Epoxy	$16,500,000	$16,500,000
Glass Fabrication Phenolic	$16,498,000	$16,498,000
Primer Zinc Chromate	$39,247,000	$39,247,000
Total Cost/Year/Subsystem		
Glass Fabrication Epoxy	$21,244,500	$21,244,500
Glass Fabrication Phenolic	$21,244,900	$21,244,900
Primer Zinc Chromate	$44,003,700	$44,003,700

Table 4.4 O&S Total phase cost-per-subsystem

	HAZMAT CTAT	DPL Model
Procurement		
Glass Fabrication Epoxy	$620	$620
Glass Fabrication Phenolic	$240	$240
Primer Zinc Chromate	$510	$510
Transportation		
Glass Fabrication Epoxy	$0	$0
Glass Fabrication Phenolic	$0	$0
Primer Zinc Chromate	$0	$0
Handling		
Glass Fabrication Epoxy	$40	$40
Glass Fabrication Phenolic	$10	$10
Primer Zinc Chromate	$40	$40
Management		
Glass Fabrication Epoxy	$1,480	$1,480
Glass Fabrication Phenolic	$600	$600
Primer Zinc Chromate	$1,080	$1,080
Training		
Glass Fabrication Epoxy	$0	$0
Glass Fabrication Phenolic	$0	$0
Primer Zinc Chromate	$0	$0
Legal/Liability		
Glass Fabrication Epoxy	$2,600	$2,600
Glass Fabrication Phenolic	$1,040	$1,040
Primer Zinc Chromate	$3,550	$3,550
Medical		
Glass Fabrication Epoxy	$881,900	$881,900
Glass Fabrication Phenolic	$363,000	$363,000
Primer Zinc Chromate	$264,500	$264,500
Facilities		
Glass Fabrication Epoxy	$0	$0
Glass Fabrication Phenolic	$0	$0
Primer Zinc Chromate	$0	$0
Support Equipment		
Glass Fabrication Epoxy	$0	$0
Glass Fabrication Phenolic	$0	$0
Primer Zinc Chromate	$0	$0
Emergency Response		
Glass Fabrication Epoxy	$0	$0
Glass Fabrication Phenolic	$0	$0
Primer Zinc Chromate	$0	$0
Disposal		
Glass Fabrication Epoxy	$620	$620
Glass Fabrication Phenolic	$240	$240
Primer Zinc Chromate	$510	$510
Personal Protection Eq		
Glass Fabrication Epoxy	$732,400	$732,400
Glass Fabrication Phenolic	$947,500	$947,500
Primer Zinc Chromate	$2,693,200	$2,693,200
Total Cost/Year/Subsystem		
Glass Fabrication Epoxy	$1,621,000	$1,621,000
Glass Fabrication Phenolic	$1,314,500	$1,314,500
Primer Zinc Chromate	$2,964,800	$2,964,800

Validation Results

The operational validation for this study was based on comparing historical data to the output from the HAZMAT CTAT. The historical data used for this study was gathered from the manufacturing process in the MDA C-17 program. The historical data came from task orders in a current government contract with MDA. This government contract is trying to capture the total LCC of hazardous materials used in the C-17 program. A subset of the total LCC is the environmental LCC which comprises the environmental cost data for the manufacturing of the airframes for the C-17.

Although these task orders contained environmental cost data, the data was in a form that was unusable for the analysis of the HAZMAT CTAT. The data needed to be in a form that had units of cost-per-year-per-subsystem. Transformations had to be made to compare costs on a cost-per-year-subsystem basis (Slusarz, 1996). Tables 4.5-4.12 contain both MDA historical data and the output from the HAZMAT CTAT using the default values inherent in the HAZMAT CTAT database. The only default values that were changed were Average Hourly Wage and Training Cost as discussed in the Chapter Three on p.3-15. The data in the tables reflect cost in 1996 dollars. The percentage differences that were left blank reflect the situation where the MDA cost was zero, but the predicted cost from HAZMAT CTAT was not-a percentage difference is inappropriate. Tables 4.5-4.12 contain:

1. Chemical name
2. NSN #
3. Output from the HAZMAT CTAT

4. Historical data from the C-17

5. Percentage difference

6. Actual difference

Table 4.5 Chemical #1 first iteration

Chemical: Wipe Solvent NSN: 005511487				
Cost Categories	MDA	HAZMAT CTAT	% difference	Actual difference
Procurement	$63	$150	138%	$87
Handling	$0	$330		$330
Training	$0	$210		$210
PPE	$70	$16,190	23029%	$16,120
Medical	$1,188	$440	-63%	$-1148
Disposal	$0	$40		$40
Legal Liability	$2	$150	7400%	$148
Total cost/year/subsystem	$1,322	$17,510	1225%	$16,188

Table 4.6 Chemical #2 first iteration

Chemical: Vapor Degreaser NSN: 081069155				
Cost Categories	MDA	HAZMAT CTAT	% Difference	Actual difference
Procurement	$432	$170	-61%	$-262
Handling	$0	$2,410		$2410
Training	$0	$20		$20
PPE	$35	$9,630	27414%	$9595
Medical	$42	$70	67%	$28
Disposal	$29	$320	100%	$291
Legal Liability	$7	$1,100	15614%	$1093
Total cost/year/subsystem	$544	$13,720	24205%	$13,176

Table 4.7 Chemical #3 first iteration

Chemical: Seal Adhesive NSN: 010935383				
Cost Categories	MDA	HAZMAT CTAT	% Difference	Actual difference
Procurement	$3,389	$10,460	208%	$7061
Handling	$0	$1,280		$1280
Training	$0	$67,750		$67,750
PPE	$1,962,500	$2,347,010	20%	$384,510
Medical	$143,516	$132,140	-8%	$-11,376
Disposal	$1	$240	23900%	$239
Legal Liability	$8	$190	2275%	$182
Total cost/year/subsystem	$2,109,414	$2,449,070	21%	$339,656

Table 4.8 Chemical #4 first iteration

Chemical: Penetrant Remover NSN: 006640387				
Cost Categories	MDA	HAZMAT CTAT	% Difference	Actual difference
Procurement	$34	$80	135%	$46
Handling	$0	$140		$140
Training	$0	$480		$480
PPE	$36	$10,670	29539%	$10,634
Medical	$1,015	$970	-4%	$-45
Disposal	$0	$100		$100
Legal Liability	$1	$60	5900%	$59
Total cost/year/subsystem	$1,085	$12,500	1052%	$11,415

Table 4.9 Chemical #5 first iteration

Chemical: Quik Freeze NSN: 004059385				
Cost Categories	MDA	HAZMAT CTAT	% Difference	Actual difference
Procurement	$69	$100	23%	$31
Handling	$0	$50		$50
Training	$0	$80		$80
PPE	$22	$11710	53127%	$11688
Medical	$4,029	$190	-9525%	$-3839
Disposal	$0	$0	0%	$0
Legal Liability	$4	$70	1650%	$64
Total cost/year/subsystem	$4,123	$12200	196%	$8077

Table 4.10 Chemical #6 first iteration

Chemical: Corrosion Inhibiting Sealant NSN: 000087198				
Cost Categories	MDA	HAZMAT CTAT	% Difference	Actual difference
Procurement	$124,823	$73,070	-41%	$-51,753
Handling	$0	$22,510		$22,510
Training	$0	$77,860		$77,860
PPE	$1,966,825	$2,347,010	19%	$380,185
Medical	$143,578	$141,940	-1%	$-1638
Disposal	$432	$850	97%	$418
Legal Liability	$75	$3,370	4393%	$3295
Total cost/year/subsystem	$2,235,732	$2,666,610	19%	$430,878

Table 4.11 Chemical #7 first iteration

Chemical: Electrical Contact Cleaning NSN: 005842957				
Cost Categories	MDA	HAZMAT CTAT	% Difference	Actual difference
Procurement	$17	$100	488%	$83
Handling	$0	$80		$80
Training	$0	$10		$10
PPE	$290	$9,300	3107%	$9010
Medical	$27	$60	122%	$33
Disposal	$0	$10		$10
Legal Liability	$0	$40		$40
Total cost/year/subsystem	$334	$9,600	2774%	$13,176

Table 4.12 Chemical #8 first iteration

Chemical: Locking Compound Primer NSN: 001818372				
Cost Categories	MDA	HAZMAT CTAT	% Difference	Actual difference
Procurement	$54	$3	-94%	$-51
Handling	$0	$0	0%	$0
Training	$0	$200		$200
PPE	$78	$15,860	20233%	$15,782
Medical	$418	$430	12%	$22
Disposal	$0	$0	0%	$0
Legal Liability	$0	$0	0%	$0
Total cost/year/subsystem	$550	$16,493	2899%	$15,943

The percentage differences and the actual difference shown in Tables 4.5-4.12 demonstrate, for all eight chemicals, that the default values inherent in the HAZMAT CTAT do not produce environmental costs close to the recorded C-17 costs. The percentage differences and the actual differences are shown together in Tables 4.5-4.12 because percentages by themselves can be misleading. For example, in Table 4.7, the disposal percentage difference was 23900%, but the actual difference was only $239. This concept of magnitude will be discussed later in this chapter. Figure 4.1 illustrates the overall picture of the data. The total cost actual differences of two chemicals, the seal adhesive and corrosion inhibiting sealant, were within the acceptable range of ± 25% (West, 1996). This ± 25% represented the percentage difference between the MDA data versus the HAZMAT data. The standard set for the operational validity was that seven of the eight chemicals had to be within ± 25%. The total cost percentage differences of the remaining chemicals are off by a delta ranging from 196% to 24205%. Figure 4.1 is graphed on a logarithmic scale and clearly illustrates the large range of percentage differences for the total cost between MDA and HAZMAT CTAT.

These large differences indicate that there could be a possible problem with either the default values or the model itself. The next step in the output data analysis is to conduct hypothesis testing as described in the Chapter Three.

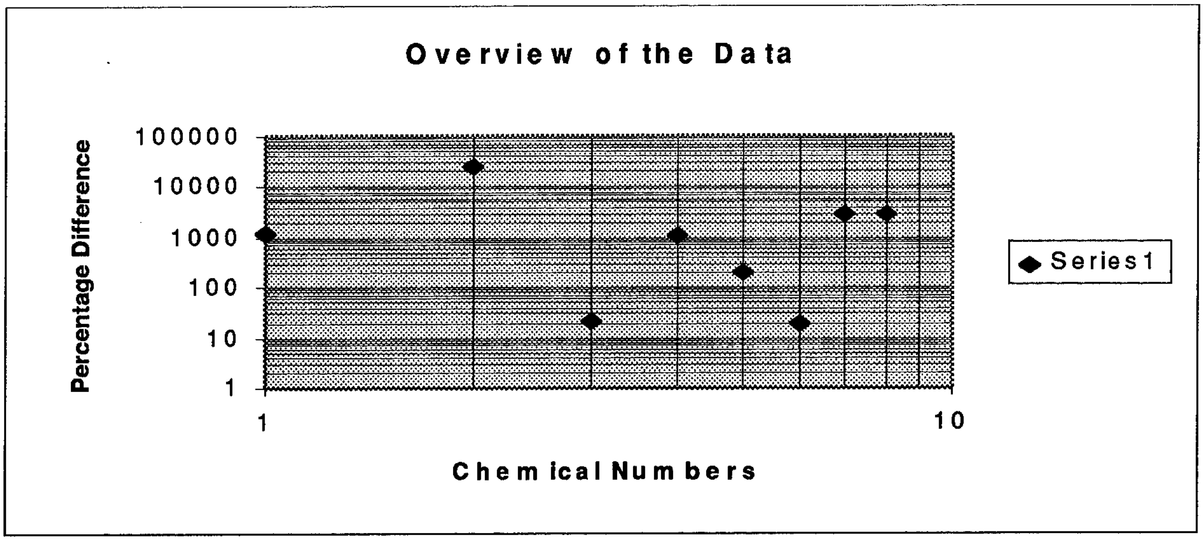


Figure 4.1 Overview of the data

The first hypothesis test conducted to check the operational validity of the HAZMAT CTAT was the one-sided one sample t test. The one sample t test was chosen to test percentage differences from the validation study. This particular hypothesis test will determine if μ, the mean of the percentage differences, can be statistically stated to be zero for a particular level of alpha.

Alpha is defined as the probability of rejecting the null when the null is true. The alpha for this test was set at .10 by Ms. Betty West, the decision-maker for this study. As alpha gets larger, the probability of rejecting the null increases. This is because the null is rejected when the calculated t, t^*, is greater than the theoretical t for a given alpha. As alpha becomes larger, the theoretical t becomes smaller, thus it is easier to reject the null. The null hypothesis for this test was that μ was equal to zero and the alternate hypothesis was that μ was greater than zero for an alpha of .10. One assumption to use a one sample t test is that the data has to be normally distributed. The Wilk-Shapiro test was used to determine if the percentage differences were normally distributed.

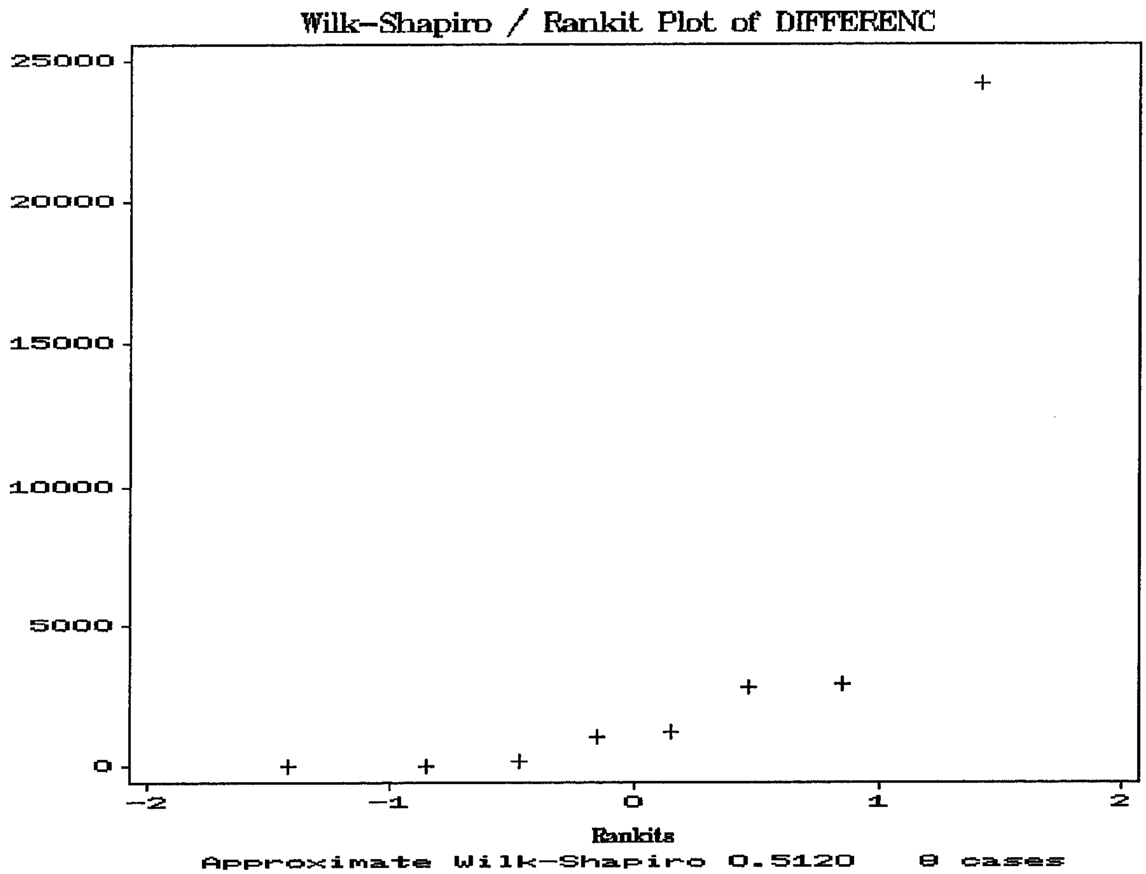


Figure 4.2 Wilk-Shapiro test results #1

The acceptable criteria for the Wilk-Shapiro test is a value of .90 or greater (Reynolds, 1996). The percentage differences for our data set failed the Wilk-Shapiro test with a value of only .5120 (See Figure 4.2).Since the percentage difference failed the Wilk-Shapiro test, the data was then analyzed to determine if the paired t-test (parametric) could be used on the actual differences for total cost between the MDA and the HAZMAT CTAT data. The goal of the paired t test was to statistically determine if μ_d , the mean of the actual differences for total cost between the MDA and HAZMAT CTAT, is zero for a level of alpha. The mean of the actual differences being zero would indicate that the total cost data from MDA and HAZMAT CTAT is statistically the same. The alpha for the two sample t test was set at .20. A two-tailed test is appropriate since the actual differences many be negative numbers.

As discussed in chapter three on p.3-18, there were six assumptions in running a paired t test. The data for study meet the four requirements, but failed the fifth requirement. The fifth requirement was that the differences of the two data sets must be distributed normally. The Wilk-Shapiro test was again conducted to test if the data was normally distributed. This time the test was conducted on the actual differences rather than the percentage differences. Again, the test failed. A value of .90 is required for aptness, but in this case the value was .6150. Figure 4.3 below depicts the results from the Wilk-Shapiro test.

Although the paired t test could not be used to test the actual differences in total cost between the MDA and HAZMAT CTAT data, the Wilcoxon Signed-Rank test, a non-parametric test, was chosen to replace the paired t-test to test the actual differences. If normality is not met on the differences, the Wilcoxon Signed-Rank test can be used to test the differences (Devore, 1995:633).

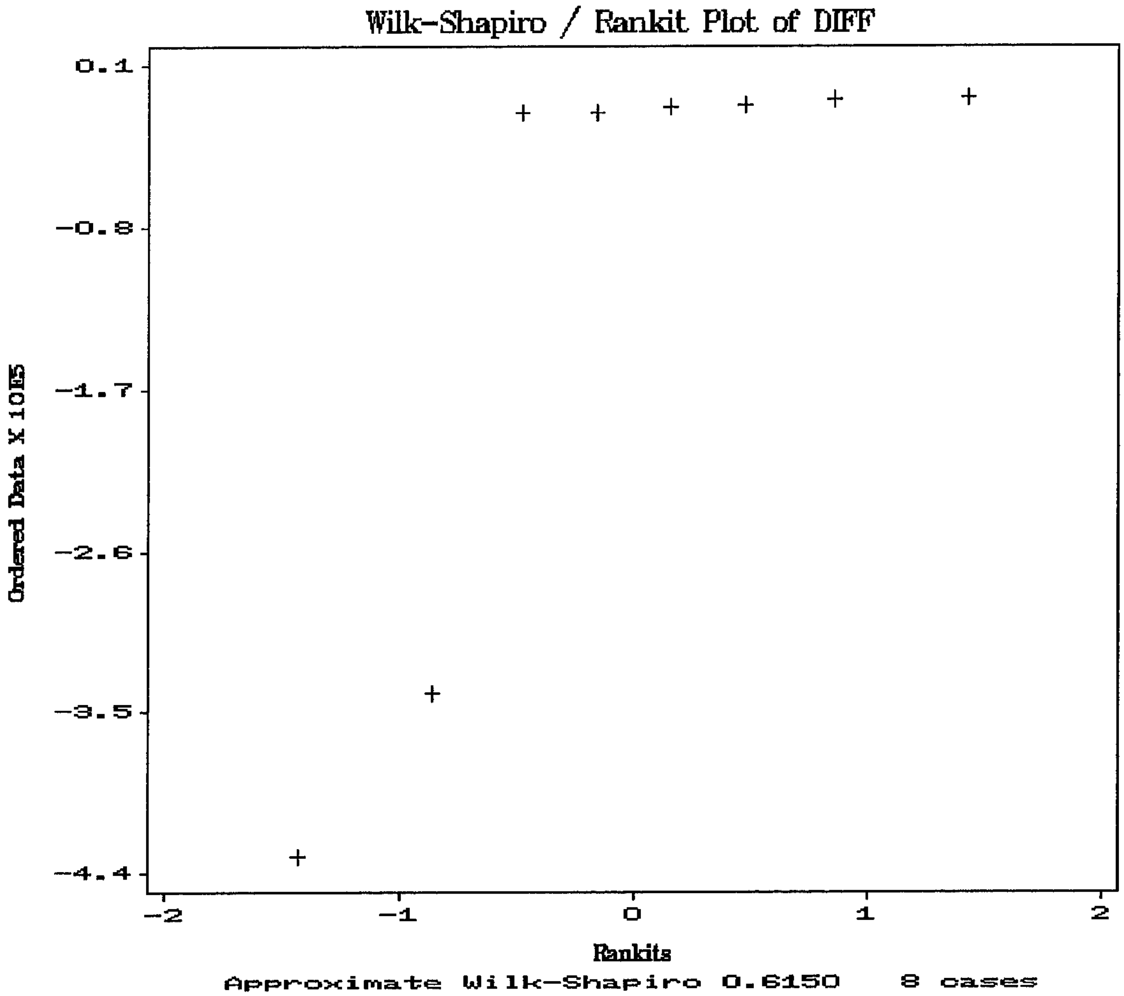


Figure 4.3 Wilk-Shapiro test results #2

In essence, the Wilcoxon Signed-Rank test is a good replacement for the paired t test when the paired t test can not be used. The Wilcoxon Signed-Rank test will test to see if there is enough evidence to suggest that the mean of the actual differences for the total cost between the MDA and HAZMAT CTAT are zero for a level of alpha. The only drawback in using a non-parametric test is that it is not as powerful as a parametric test, but the actual difference in power is often not great (Devore, 1995:634). This is because there are less restrictions in using the non-parametric test. The two requirements for using the Wilcoxon Signed-Rank test are that the data has to be continuous and symmetric. The data meets the continuous requirement, but the symmetry requirement had to be checked using a box and whisker plot (See Figure 4.4).

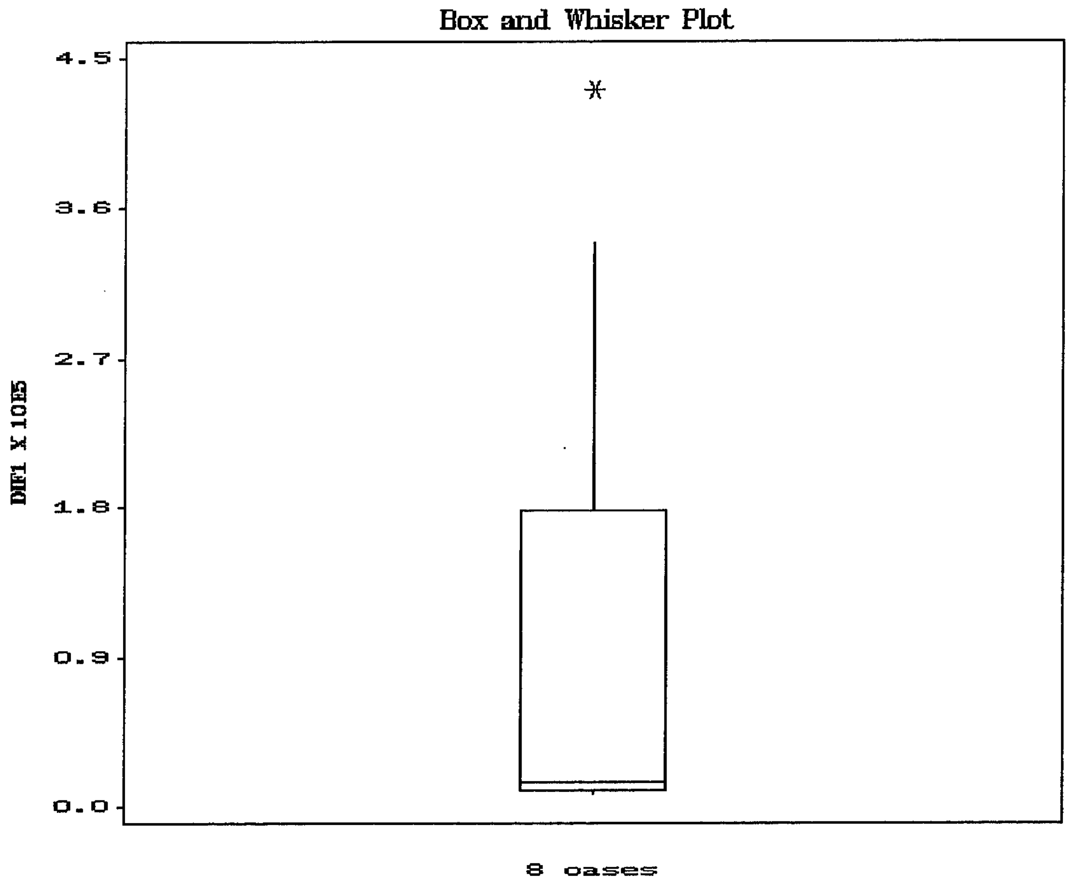


Figure 4.4 Box and whisker plot #1 first iteration

Figure 4.4 suggests that the actual differences are not symmetrical. The line inside the box in Figure 4.4 is the location of the median of the data. The fact that the median is located near the bottom of the box suggests that the data is skewed to that direction. The asterisk in the graph depicts an outlier in the data set. The outlier suggests that there could be two different populations in the actual differences for total cost between the MDA and

HAZMAT CTAT data. Figure 4.5 clearly illustrates the data to be asymmetrical. The x-axis is the actual difference for total cost and the y-axis is frequency. Due to a lack of symmetry, the Wilcoxon Signed-Rank test could not be used for the actual differences for total cost.

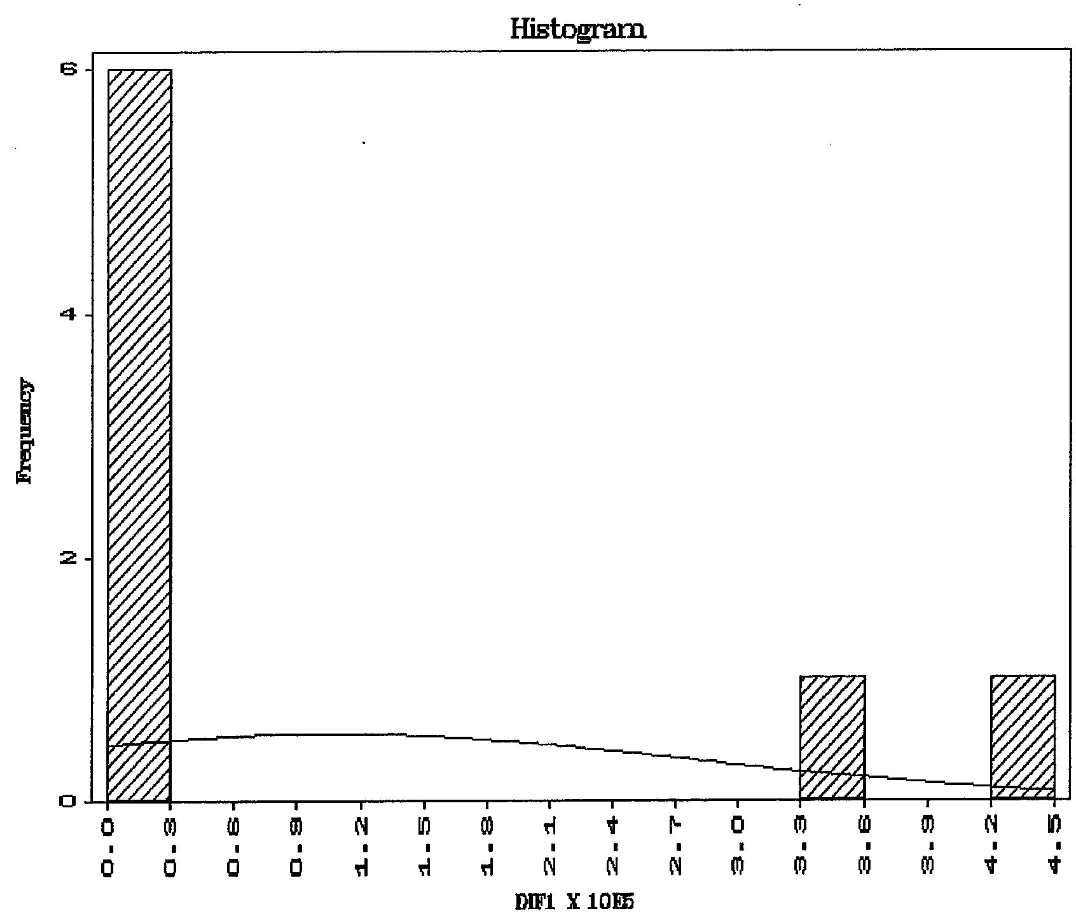


Figure 4.5 Histogram #1 first iteration

Although the data using the default numbers did not meet the requirement for hypothesis testing, descriptive statistics provides a good overall picture of the data. The actual differences for total cost had a sample mean of $105,575 and a sample standard deviation of $174,400. The percentage difference sample mean was 4049%. These high values indicate that the actual difference and percentage difference may be significant for the total cost between MDA and HAZMAT CTAT data. From the all indications, the HAZMAT CTAT predicted values do not seem to resemble the MDA historical cost. Not only are the percentage differences and actual differences means significantly high, all the predicted estimates were considerably larger than the historical data.

There were two noticeable trends prevalent in the validation data. First, it seems that the HAZMAT CTAT gets closer to the historical data as the total cost-per-year-subsystem increases. Second, it seems that the HAZMAT CTAT gets closer to the historical data as the number of people increases in the process. Figure 4.6 and 4.7 illustrate this point. Figure 4.6 depicts the relationship between total cost-per-year-per-subsystem and the percentage difference for total cost and Figure 4.7 depicts the relationship between the number of people in the process and the percentage difference for total cost. These figures were done in log-log scale because of the large range of values in the data.

The trend analysis graphs above indicate that the differences between HAZMAT CTAT data and MDA reported data decrease as the total cost-per-year-per-subsystem or the number of people in the process increases. This can be seen by the asymptotic shape of the curve. These graphs depict an inverse relationship between the total cost-per-year-per-subsystem and percentage difference and the number of people and percentage difference. The two points which meet the maximum of 25% were chemicals that were over $2M and had over 6000 people in the process.

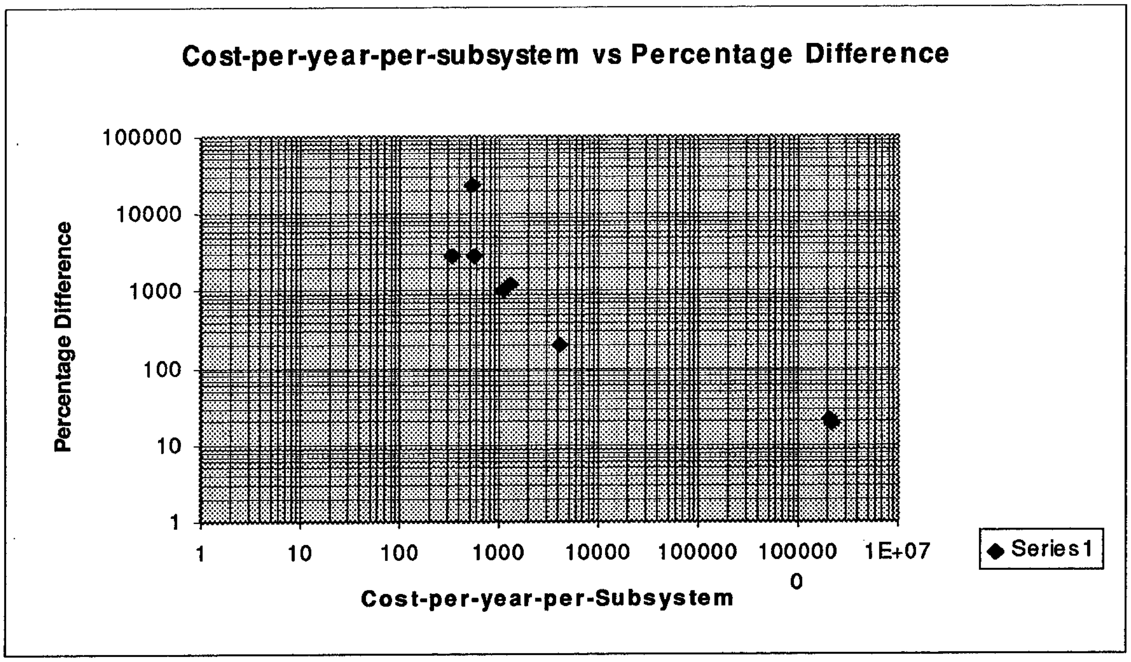


Figure 4.6 Cost-per-year-per-subsystem vs percentage difference

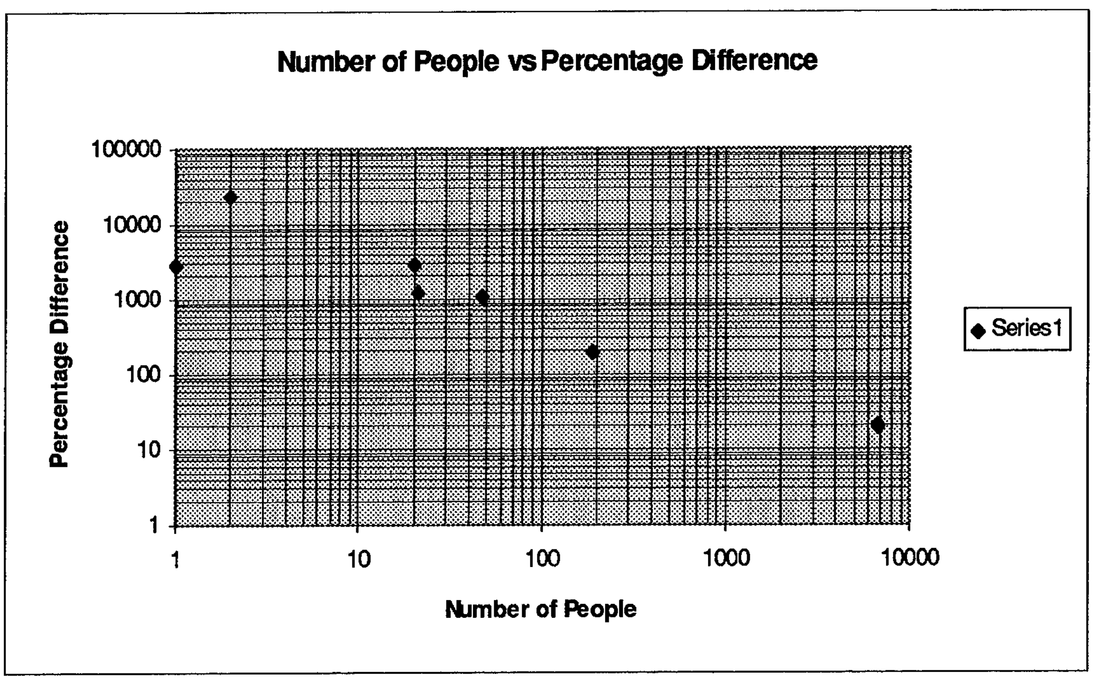


Figure 4.7 Number of people vs percentage difference

This relationship indicates that the HAZMAT CTAT may be more suited for larger type of estimates rather than estimates that involve minimal cost or people. Although more data points are necessary to conclusively confirm this relationship, the two trends do indicate that there might be a threshold or constraint on when the model could be used. This relationship could be an important limitation to the HAZMAT CTAT.

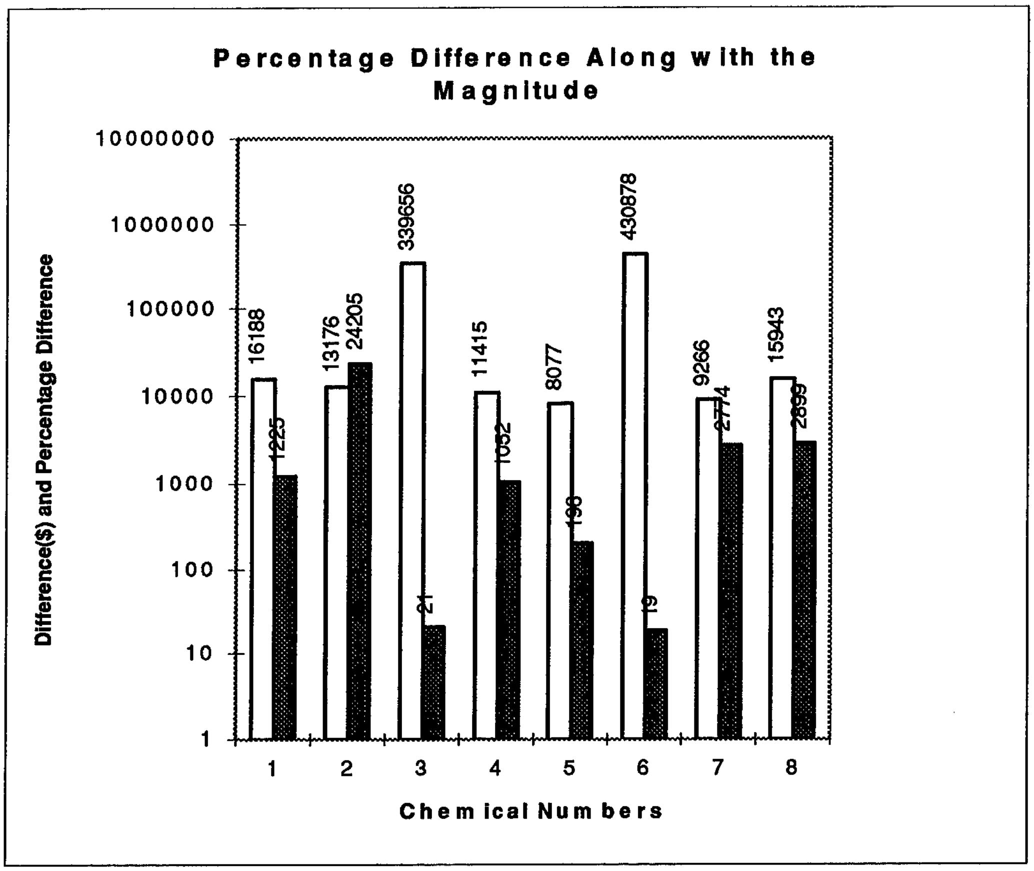


Figure 4.8 Percentage differences with the magnitudes

Also important is the idea of magnitude, as stated earlier. Although, the two chemicals with the largest total cost were within the required delta of ± 25%, these two had the two largest actual differences for total cost. Figure 4.8 shows the relationship between the total cost percentage difference and the magnitude of those percentage differences for all eight chemicals. The dark bar on the right reflect percentage difference and the light bar to the immediate left reflect the actual difference. Figure 4.8 shows that just percentage differences can be misleading. Chemical #2 has a percentage difference of 24205%, but the magnitude of the actual difference is only $13,176, while chemical #6 has the lowest percentage difference at 19%, but the actual difference is $430,878. This shows that even though a chemical might be within a set percentage difference, it can be misleading unless the magnitude of the difference is also reported. For this study, Ms. Betty West was only concerned about the percentage difference between MDA and HAZMAT CTAT data, but Figure 4.8 indicates that magnitudes should also be considered as part of any analysis.

Conceptual Model Validity Results

The goal of the section is to analyze the assumptions or theories inherent in the HAZMAT CTAT that could be responsible for the differences with the MDA historical data and to identify concerns with the model.

<u>Possible Sources for Differences in the Validation Study</u>

1. Uncertainty in Default Values

A potential source for the differences in the validation study could be the accuracy of the default values inherent in the database, particularly the PPE cost. Table 4.13 illustrates the average percentage differences and average actual differences for total cost for the eight chemicals. The blanks in percentage difference column indicate that a percentage difference was inappropriate.

Table 4.13 Average percentage and actual difference

Cost Categories	% difference	Actual difference
Procurement	149%	$7422
Handling		$3350
Training		$18,326
PPE	19,561%	$105,942
Medical	1225%	$3626
Disposal	4819%	$137
Legal Liability	4105%	$610
Total cost/year/subsystem	4049%	$105,575

The cost category that sticks out immediately is the PPE cost category. The PPE is responsible for the largest percentage difference and actual difference, so the PPE cost category merits further investigation.

The PPE cost category in the HAZMAT CTAT consists of direct and indirect components. The direct cost component is from the actual cost of the equipment. The indirect cost component is from what the HAZMAT CTAT describes as work loss and dispensing and tracking. The important factors important to work loss and dispensing and tracking are the following:

1. The time lost (TL) factor in the work loss cost calculations
2. The time worn (TW) factor in the work loss cost calculations
3. The dispensing and tracking (DT) factor the dispensing and tracking calculations

The TL factor is defined in the HAZMAT CTAT user's guide as the percentage of time that is unproductive resulting from acquiring, maintaining, using, and recommending PPE (TASC, 1996:75). The DT factor is defined in the HAZMAT CTAT user's guide as the cost for dispensing and tracking of PPE per year for a given process (TASC, 1996:75). The TW factor is defined in the HAZMAT CTAT user's guide as the percentage of time per year that a worker wears the particular PPE (TASC, 1996:75). All these factors try to measure the indirect cost of PPE for a given process.

In the MDA environmental cost calculations, the majority of the PPE cost is from the direct cost of PPE and not the indirect cost. The spreadsheet that calculates the MDA environmental cost indicates the PPE cost for most of the chemicals are attributed to the cost of the equipment for the people in the process. The reason that MDA did not try to account for the indirect of PPE is that MDA was unsure how to measure the indirect effect of wearing PPE (Slusarz, 1996). Dr. Long, the model developer, had the same concern for the indirect effects in the HAZMAT CTAT from the effect of wearing PPE.

Dr. Long states that the TL, TW, an DT factors used to measure the indirect effects of wearing PPE was his biggest concern due to the uncertain nature of these factors (Long, 1996). The indirect effects of PPE are uncertain because there have been no studies to accurately support the indirect effects of wearing PPE in the workplace. Dr. Long tried to implement the indirect effects of wearing PPE even though the indirect effects of PPE were unknown.

Compounding the effect of this uncertainty is the fact that the TW, TL, and DT factors are include in the top ten most influential factors in the HAZMAT CTAT. The top ten list is shown on p.4-46. Since the MDA cost does not rely heavily on these three factors in their calculations, the eight chemicals were recalculated in the HAZMAT CTAT using modified factors for the TL, TW, and DT factors to reflect the method in which MDA calculated their environmental cost. The overall goal of these modifications is to see if the deltas between the MDA and HAZMAT CTAT data decrease for total cost and PPE with less emphasis on these factors. If the deltas decrease dramatically, it suggests that the HAZMAT CTAT overemphasizes the indirect effects of wearing PPE compared to MDA. Tables 4.14 shows the original default values and the new modified values to reflect the MDA cost factors.

Table 4.14 Default modifications

Chemical 1	Original	Modified	Chemical 5	Original	Modified
TL (hand)	0.01	0	TL (hand)	0.01	0
TL (eye)	0.09	0	TL (eye)	0.09	0
DT	0.86	0.2	DT	0.86	0.2
Chemical 2			Chemical 6		
TL (hand)	0.01	0	TL (hand)	0.01	0.02
TL (eye)	0.09	0	TL (eye)	0.09	0.02
DT	0.86	0.2	DT	0.86	0.2
Chemical 3			Chemical 7		
TL (hand)	0.01	0.02	TL (hand)	0.01	0
TL (eye)	0.09	0.02	TL (eye)	0.09	0
DT	0.86	0.2	DT	0.86	0.2
Chemical 4			Chemical 8		
TL (hand)	0.01	0	TL (hand)	0.01	0
TL (eye)	0.09	0	TL (eye)	0.09	0
DT	0.86	0.2	DT	0.86	0.2

Tables 4.15-4.22 shows the new HAZMAT CTAT output using the modified values for PPE . The tables below illustrate the following information:

1. Chemical name

2. NSN #

3. Output from the HAZMAT CTAT with the modification of the TL and DT

4. Historical data from the C-17

5. Percentage difference

6. Actual difference

Table 4.15 Chemical #1 second iteration

Chemical; Wipe Solvent NSN: 005511487				
Cost Categories	MDA	HAZMAT CTAT	% Difference	Actual difference
Procurement	$63	$150	138%	$87
Handling	$0	$330		$330
Training	$0	$210		$210
PPE	$70	$2,230	3086%	$70
Medical	$1,188	$440	-63%	$-748
Disposal	$0	$40		$40
Legal Liability	$2	$150	7400%	$148
Total cost/year/subsystem	$1,322	$3,550	169%	$2228

Table 4.16 Chemical #2 second iteration

Vapor Degreaser NSN: 081069155				
Cost Categories	MDA	HAZMAT CTAT	% Difference	Actual difference
Procurement	$432	$160	-60%	$-272
Handling	$0	$0	0%	$0
Training	$0	$20		$20
PPE	$35	$1,950	5471%	$1915
Medical	$42	$70	67%	$28
Disposal	$29	$320	100%	$291
Legal Liability	$7	$440	6186%	$333
Total cost/year/subsystem	$544	$2,960	444%	$2416

Table 4.17 Chemical #3 second iteration

Chemical: Seal Adhesive NSN: 010935383				
Cost Categories	MDA	HAZMAT CTAT	% Difference	Actual difference
Procurement	$3,389	$10,460	208%	$7071
Handling	$0	$1,280		$1280
Training	$0	$67,750		$67,750
PPE	$1,962,500	$1,811,700	-8%	$-150,800
Medical	$143,516	$132,140	-8%	$-11,376
Disposal	$1	$240	23900%	$239
Legal Liability	$8	$190	2275%	$182
Total cost/year/subsystem	$2,109,414	$2,023,760	-4%	$-85,654

Table 4.18 Chemical #4 second iteration

Chemical: Penetrant Remover NSN: 006640387				
Cost Categories	MDA	HAZMAT CTAT	% Difference	Actual differenc e
Procurement	$34	$80	135%	$46
Handling	$0	$140		$140
Training	$0	$480		$480
PPE	$36	$2,120	5789%	$2084
Medical	$1,015	$970	-4%	$-45
Disposal	$0	$100		$100
Legal Liability	$1	$60	5900%	$59
Total cost/year/subsystem	$1,085	$3,950	264%	$2865

Table 4.19 Chemical #5 second iteration

Chemical: Quik Freeze NSN: 004059385				
Cost Categories	MDA	HAZMAT CTAT	% Difference	Actual difference
Procurement	$69	$100	45%	$31
Handling	$0	$50		$50
Training	$0	$80		$80
PPE	$22	$2,140	9627%	$2118
Medical	$4,029	$190	-95%	$-3839
Disposal	$0	$0	0%	$0
Legal Liability	$4	$70	1650%	$66
Total cost/year/subsystem	$4,123	$2,630	-36%	$-1493

Table 4.20 Chemical #6 second iteration

Chemical: Corrosion Inhibiting Sealant NSN: 000087198				
Cost Categories	MDA	HAZMAT CTAT	% Difference	Actual difference
Procurement	$124,823	$73,070	-41%	$-51,753
Handling	$0	$22,510		$22,510
Training	$0	$67,750		$67,750
PPE	$1,966,825	$1,811,700	-8%	$-155,125
Medical	$143,578	$141,940	-1%	$-1638
Disposal	$432	$850	97%	$418
Legal Liability	$75	$3,370	4393%	$3295
Total cost/year/subsystem	$2,235,732	$2,131,300	-5%	$-104,432

Table 4.21 Chemical #7 second iteration

Chemical: Electrical Contact Cleaning NSN: 005842957				
Cost Categories	MDA	HAZMAT CTAT	% Difference	Actual difference
Procurement	$17	$100	488%	$83
Handling	$0	$80		$80
Training	$0	$10		$10
PPE	$290	$2,100	624%	$1810
Medical	$27	$60	122%	$33
Disposal	$0	$10		$10
Legal Liability	$0	$40		$40
Total cost/year/subsystem	$334	$2,400	619%	$2066

Table 4.22 Chemical #8 second iteration

Chemical: Locking Compound Primer NSN: 001818372				
Cost Categories	MDA	HAZMAT CTAT	% Difference	Actual difference
Procurement	$54	$3	-94%	$-51
Handling	$0	$0	0%	$0
Training	$0	$229		$229
PPE	$78	$2,230	2759%	$2152
Medical	$418	$430	3%	$12
Disposal	$0	$0	0%	$0
Legal Liability	$0	$0	0%	$0
Total cost/year/subsystem	$550	$2,892	426%	$2342

The modifications to the TL and DT made some dramatic decreases to the deltas between the MDA and the HAZMAT CTAT Total Cost data. Table 4.23 below shows the deltas using the default values and modified values along with the actual difference for the total cost for the eight chemicals .

Table 4.23 Comparison of deltas

Chemicals	Deltas w/ default factors	Actual difference	Deltas w/ modified factors	Actual difference
1	1225%	$16,188	169%	$2228
2	24205%	$13,176	444%	$2416
3	21%	$339,656	4%	$85,654
4	1052%	$11,415	264%	$2865
5	196%	$8077	36%	$1493
6	19%	$430,878	5%	$104,432
7	2774%	$9266	619%	$2066
8	2899%	$15,943	426%	$2342
Ave	4049%	$105,575	246%	$25,437

The percentage differences along with the actual differences between the MDA and HAZMAT data for total cost decrease dramatically using the modified factor for TL and DT. Even with the modifications, only chemicals #3 and #6 fall within the ± 25% delta for total cost. These were the same chemicals that were within ± 25% using the default values. Table 4.23 indicates that the percentage differences for total cost decreased by an order of magnitude by modifying the indirect cost associated with PPE. The data seems to suggest, but not definitively, that the indirect cost of PPE may be overemphasized in the HAZMAT CTAT. More research is required on the effects of wearing PPE in the manufacturing process.

The same hypothesis tests that were considered for default value data in the operational validation section was considered for the new data with the modified values. Earlier, the one sample t test could not be used on the percentage differences using default values because the percentage differences failed the Wilk-Shapiro test, but the percentage differences with the modified data passed the Wilk-Shapiro normality test. Figure 4.9 shows the results of the Wilk-Shapiro test. The passing value required from a Wilk-Shapiro test is .9, Figure 4.9 shows that the value percentage differences with the modified factors is .9258. Since normality was not rejected, a one sample t test was conducted on the percentage differences using Statistix 4.1 software. As stated earlier, the one sample hypothesis test will determine if data suggests that μ, the mean of the percentage differences, is centered around zero. The alpha for this test was set at .10 by Ms. Betty West, the decision-maker for this study.

The null hypothesis for this test was that μ was equal to zero and the alternate hypothesis was that μ was greater than zero for an alpha of .10. Hence, if we reject the null, we are 90 percent sure that we made the correct decision. The t^* from the output of Statistix 4.1 was 2.99. The theoretical t was gathered from the book *Probability and Statistics for Engineering and Sciences* by Devore.

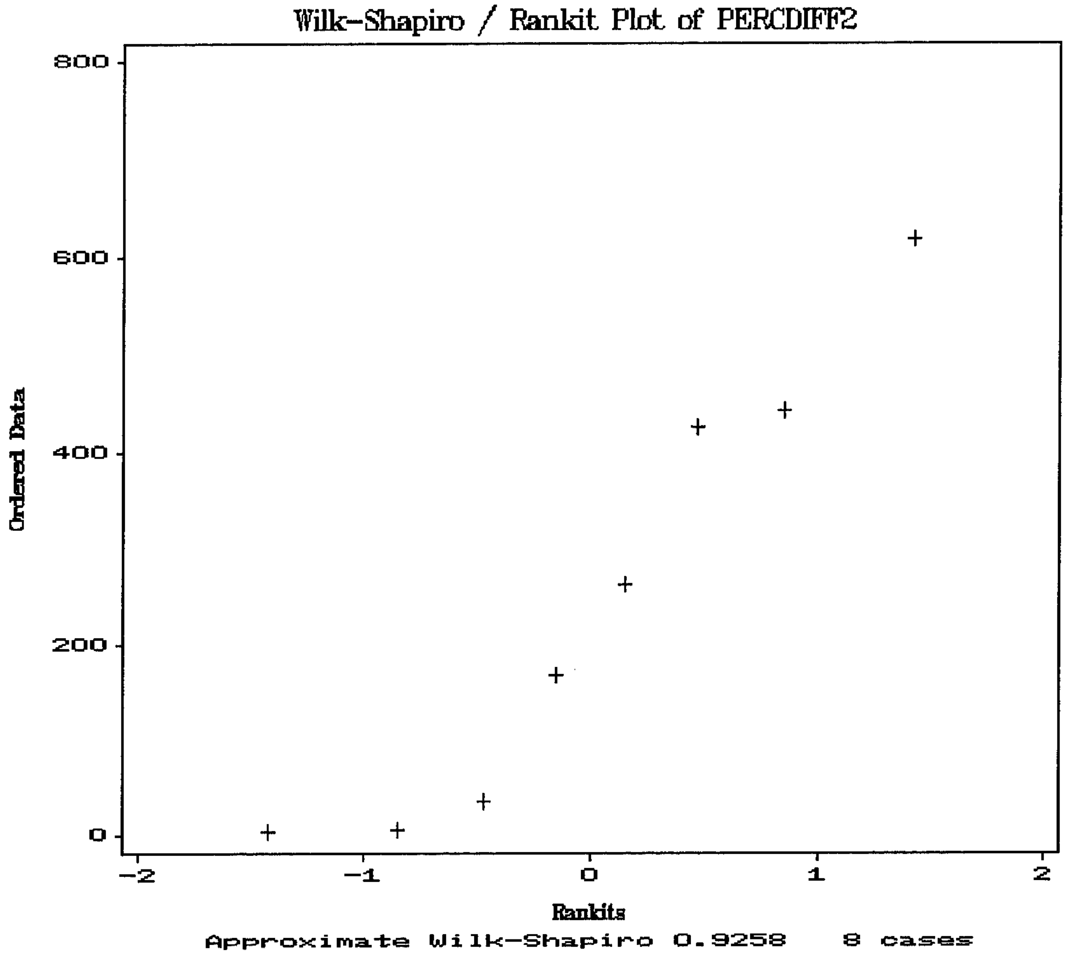


Figure 4.9 Wilk-Shapiro test results #3

In Appendix Table A.5 in this book, the theoretical t is stated as 1.415 for an alpha of .10. For the null to be rejected, t* must to be greater than 1.415. In this case, 2.99 is greater than 1.415 so the null is rejected. This suggest that there is not enough evidence to say that the percentage differences are centered around zero for an alpha of .10.

Next, the two sample hypothesis test was considered. Again, the actual differences for total cost failed the Wilk-Shapiro normality test.

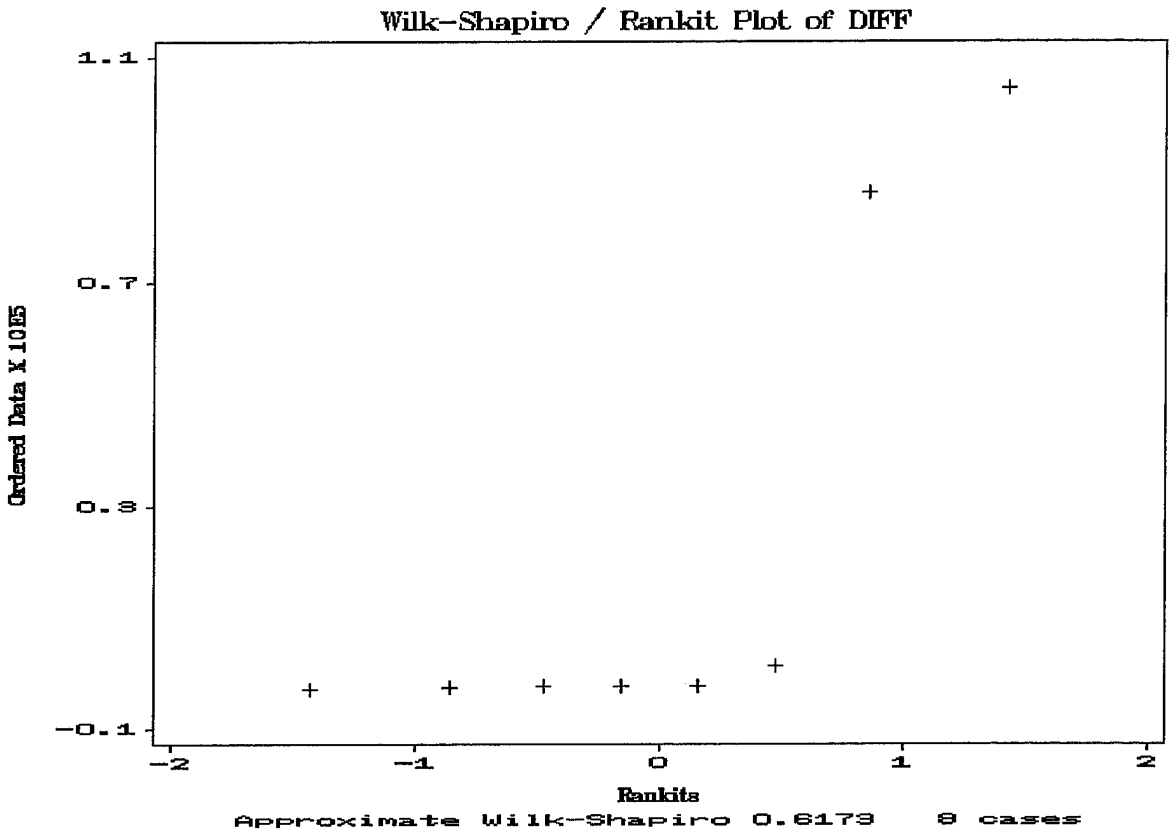


Figure 4.10 Wilk-Shapiro test results #4

Figure 4.10 shows the Wilk-Shapiro test result to be .6178, short of the required .90. Since the data did not pass the Wilk-Shapiro normality test, the Wilcoxon Signed-Rank test had to be considered again as an alternative to the paired t-test.

The two requirements for using the Wilcoxon Signed-Rank test are that the data has to be continuous and symmetric. The data meets the continuous requirement, but the symmetry requirement had to be checked using a box and whisker plot (See Figure 4.11). Figure 4.11 suggests that the data with the modified factors are not symmetrical. The box and whisker diagram suggests that the data is skewed toward the bottom of the box, but this time there are no outliers suggesting that the actual differences for total cost with the modified values are from a different population.

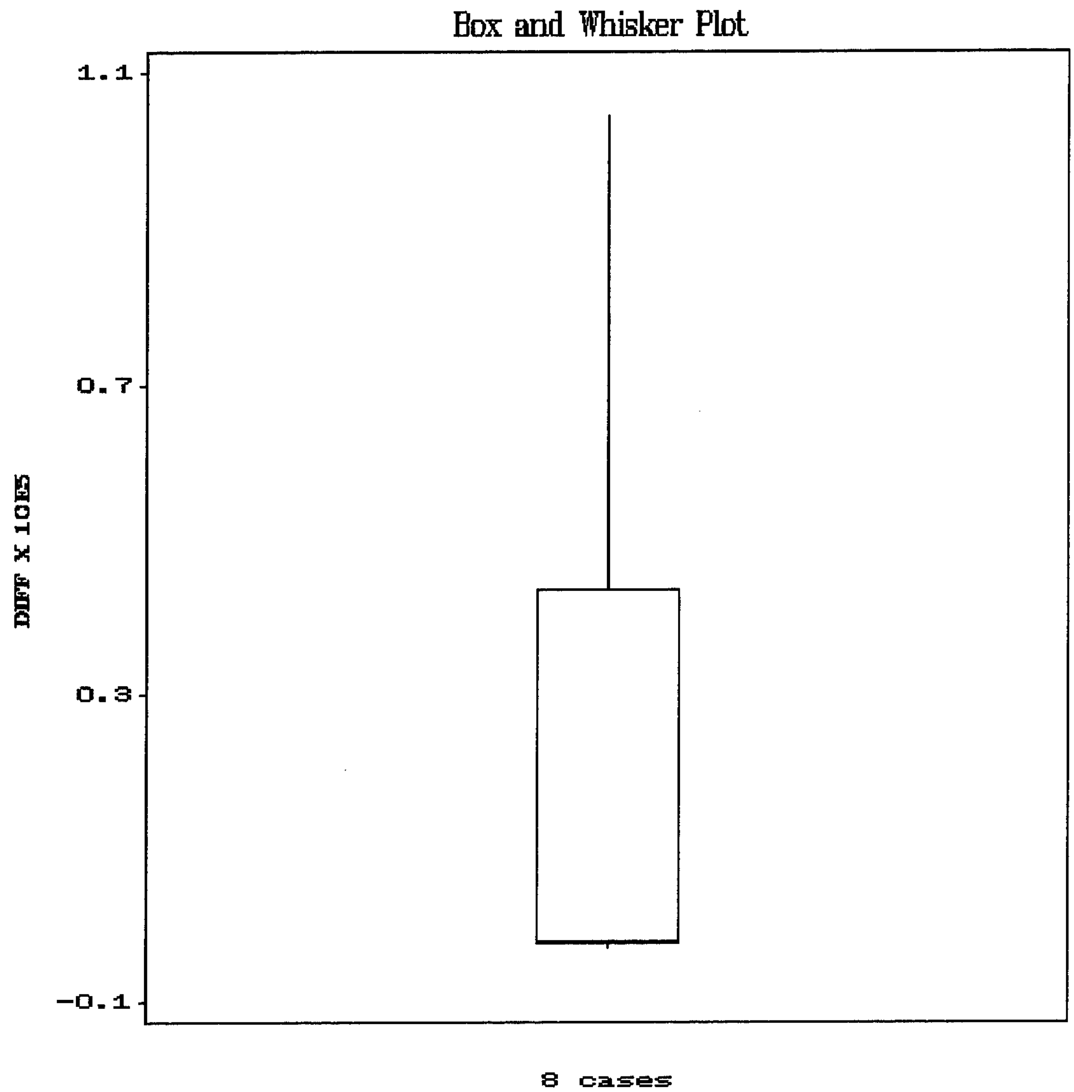


Figure 4.11 Box and whisker plot #2

Again the data need not meet the requirements to conduct any hypothesis testing, but Table 4.23 suggests that the modification to the default values in the PPE category made an significant improvement in resembling historical data.

The two trends that were relevant using the default values were also relevant using the modified values. Figures 4.12 and 4.13 illustrates that fact the trend was the same for the values with the modified factors. Figures 4.12 and 4.13 were graphed on log-log scale because of the large range of values. Again, as the total cost-per-year-per-subsystem and number of people increase, the percentage difference for total cost decreases. As suggested earlier, there might a threshold or constraint as to when the HAZMAT CTAT may be used if a maximum of ± 25% is required.

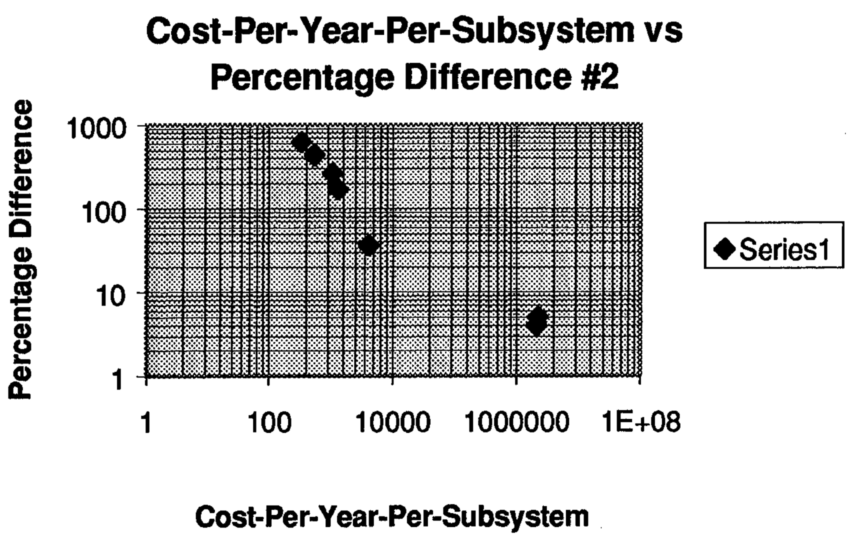


Figure 4.12 Cost-per-year-per-subsystem vs percentage difference

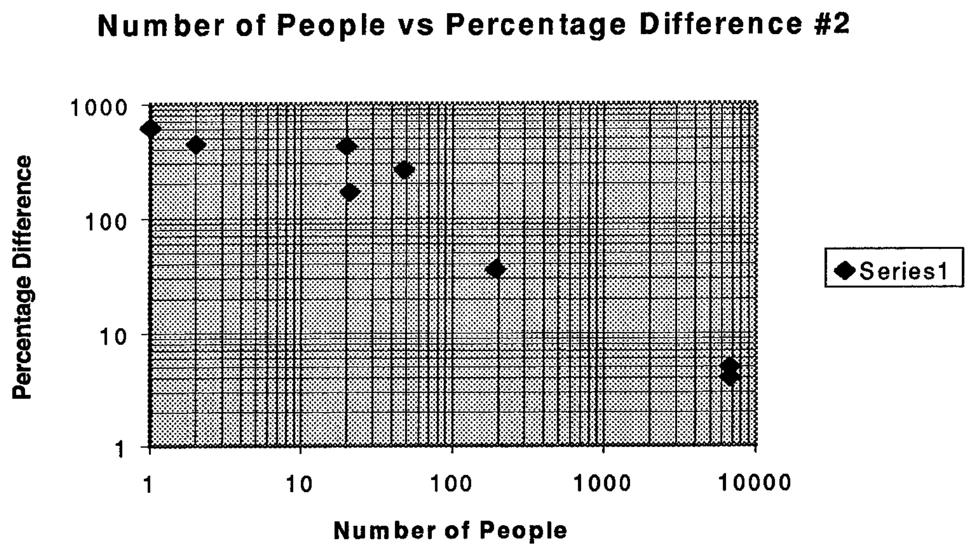


Figure 4.13 Number of people vs percentage difference

2. User Knowledge

One of the assumptions inherent in the HAZMAT CTAT is that the user has the ability and knowledge to correctly change the default values to meet their particular situation. This assumption comes from the fact that there are no directions in the User's guide concerning changing default values. The rationale for making the HAZMAT CTAT a windows operated program was so that the user could change all the default values inherent in the HAZMAT CTAT. This flexibility can lead to a possible source of error using the HAZMAT CTAT.

A good example in this particular study is chemical #2. This particular chemical has some unique circumstances and if the user is not aware of these unique features, inaccurate costs would be calculated. The unique quality of chemical #2 is that it is part of a process that requires a large amount of hazardous materials, but requires only one operator. By inputting such a large quantity of hazardous materials into the HAZMAT CTAT, cost factors such as handling and potential legal liability overestimate costs due to the large quantity. HAZMAT CTAT correlates high quantity of hazardous materials with high handling and potential legal liability cost. Although a large quantity of hazardous materials may suggest a high environmental cost for some categories, the contrary is true for the costs associated with handling and potential legal liability since only one person is in the process.

After discussing this situation with Dr. Long, changes were made to correctly reflect the cost factors for handling and potential legal liability. The original factor used for handling and potential legal liability was 2.85 and 7.517. The modified factors were 0 and 2.517, respectively, to reflect the accurate scenario for chemical #2. Tables 4.24 and 4.25 below represent the cost with and without the modifications.

Table 4.24 Chemical # 2 w/ default values

Chemical: Vapor Degreaser NSN: 081069155			
Cost Categories	MDA	HAZMAT CTAT	% Difference
Procurement	$432	$170	-61%
Handling	$0	$2,410	
Training	$0	$20	
PPE	$35	$9,630	27414%
Medical	$42	$70	67%
Disposal	$29	$320	100%
Legal Liability	$7	$1,100	15614%
Total cost/year/subsystem	$544	$13,720	24205%

Table 4.25 Chemical #2 w/ modified factors

Vapor Degreaser NSN: 081069155			
Cost Categories	MDA	HAZMAT CTAT	% Difference
Procurement	$432	$160	-60%
Handling	$0	$0	0%
Training	$0	$20	
PPE	$35	$1,950	5471%
Medical	$42	$70	67%
Disposal	$29	$320	100%
Legal Liability	$7	$440	6186%
Total cost/year/subsystem	$544	$2,960	444%

Notice the large difference between the two costs. The total cost difference decreases from $13,176 to $2,416. That is a considerable amount of difference. The assumption that the user has enough knowledge to correctly input the right factors can be dangerous because the potential error can be extremely large.

This assumption is compounded by the fact that the program uses these default values without explaining what the numbers actually mean. Even in situations where the user has knowledge of the process, modifying the default values correctly would be extremely difficult. For example, what does a 2.59 factor for handling mean? What is the basis for using 2.59 for handling? How can someone make any accurate modifications? A guide needs to be developed so that users can properly change the default values and evaluators can check for questionable default values

3. Extrapolation

The HAZMAT CTAT was developed so that all the planes in a particular category can be analyzed for environmental costs. For example, the categories for planes in the

HAZMAT CTAT include cargo and fighter. The developers wanted to produce a generic category so that every plane in the inventory could be analyzed without having data from every plane. The problem with this concept is that only one plane per category was analyzed to represent that whole category of planes. For the cargo planes, data was gathered from the C-130 aircraft to represent all the cargo planes in the inventory. The way the HAZMAT CTAT relates this data to other cargo planes is through extrapolation of surface area of a plane. The model assumes that the larger surface area equates to a higher environmental cost. This extrapolation theory is a possible source of error in the HAZMAT CTAT.

For example, in this thesis, the C-17 was analyzed which has a much larger surface area than the C-130. The default surface area in the HAZMAT CTAT is 7,590 square feet which is the surface area of the C-130. The C-17 surface area is 22,371 square feet (Slusarz, 1996). The HAZMAT CTAT extrapolates the environmental cost using the ratio of these two surface areas. The ratio for this study was 22,371 divided by 7,590 which equals 2.95. The HAZMAT CTAT uses this surface area ratio to extrapolate from the C-130 to the C-17.

To test the accuracy of the surface area extrapolation, chemical #1 was recalculated using the original 7,590 square feet to determine if using the original surface area produced numbers closer to the MDA cost data.

Table 4.26 C-17 surface area results

Chemical: Wipe Solvent NSN: 005511487				
Cost Categories	MDA	HAZMAT CTAT	% difference	Actual difference
Procurement	$63	$150	138%	$87
Handling	$0	$330		$330
Training	$0	$210		$210
PPE	$70	$16,190	23029%	$16,120
Medical	$1,188	$440	-63%	$-1148
Disposal	$0	$40		$40
Legal Liability	$2	$150	7400%	$148
Total cost/year/subsystem	$1,322	$17,510	1225%	$16,188

Table 4.27 C-130 surface area results

Chemical: Wipe Solvent NSN: 005511487				
Cost Categories	MDA	HAZMAT CTAT	% difference	Actual difference
Procurement	$63	$50	21%	$-13
Handling	$0	$110		$110
Training	$0	$210		$210
PPE	$70	$16,190	23029%	$16,120
Medical	$1,188	$440	-63%	$-1148
Disposal	$0	$10		$10
Legal Liability	$2	$50	2400%	$48
Total cost/year/subsystem	$1,322	$17,060	1190%	$15,738

Table 4.26 shows the original results from using the default values and the actual C-17 surface area and Table 4.27 shows the results from using the default values and the C-130 surface area.

Although the use of the C-130 surface area produce minor improvements in the total cost percentage difference and total cost actual difference, other cost categories had significant improvements. The percentage difference for procurement improved 117% and legal liability improved 5000%. Also the actual differences for handling and disposal decreased due to the use of the C-130 surface area. This indicates that the extrapolation theory might be incorrect for cargo aircraft since using the C-17 surface area result in larger discrepancies with the MDA historical data. The extrapolation might be incorrect because the data was gathered from how the C-130 was manufactured by Martin Marietta. The C-17 is manufactured by MDA. The extrapolation theory assumes that the data for Martin-Marietta is relevant to MDA. This assumption might be wrong because MDA might be more efficient than Martin-Marietta and thus the extrapolation would cause MDA cost data to deviate further from their specific scenario.

4. Lack of Specific Processes in the Cargo Category

The HAZMAT CTAT typically allows the user to analyze all the different processes involved in the manufacturing process, except for cargo planes. For cargo aircraft, the user can choose only one process; aircraft production. Due to this limitation, all the sub-processes involved in the production of cargo aircraft uses the data gathered for the overall production of the aircraft. The reason for this limitation on cargo aircraft is that the developers were limited to the amount of data available from the C-130 Martin-Marietta plant. Using the same factors for a plating operation and a paint operation pose a significant problem. They are entirely different operations and require factors that are unique to that process. This assumption that data from the overall production of an aircraft is same as the data for a different sub-process is a possible source of error in the calculation of cost associated with hazardous materials. For example, in the fighter aircraft category for the operational and support phase, different sub-processes reflect the factors for those specific processes. The AFA Base Corrosion Control process has a handling factor of 0 and a management factor of 23.96, while the AFA Depot Electrical Repair process has a handling factor of 3.271 and a management factor of .027. Each sub-process has factors relevant to that process. The same must be done for the cargo aircraft category for the manufacturing phase.

Apparent Deficiencies of the HAZMAT CTAT

1. Lack of a Cost Category Evaluating the Cost of Changing Regulations and Technical Orders

The HAZMAT CTAT promotes its ability as a cost trade-off analysis tool. As a cost trade-off tool, it aids the user in deciding if one chemical should be used over another. One of the deficiencies apparent in the HAZMAT CTAT is a cost category concerning the cost for changing regulations and technical orders if the other chemical is chosen over the existing chemical. The changing of regulations and technical orders is labor intensive activity. This cost should be disclosed to the user of the HAZMAT CTAT so that decisions concerning chemical replacement are based on a holistic basis. Not everyone will want the cost from each category, but having that option is necessary for people that want the whole picture before making their decisions.

2. PPE Total Phase Cost

Although this validation study was centered around the environmental cost of hazardous materials for a single year, the HAZMAT CTAT was developed to look also at the LCC of hazardous materials. In doing these LCC calculations, the HAZMAT CTAT has one major deficiency in calculating the cost of PPE. As explained before, the cost of

PPE is one of the main cost drivers for the HAZMAT CTAT model. The reason for the PPE cost being one of the main cost drivers in the model can be attributed to the fact that uncertainty exists in the accuracy of TL, TW, and DT factors. Compounding this problem is the fact that the HAZMAT CTAT assumes that new PPE will be bought every year. This assumption is questionable. Respirators usually last several years. People do not buy respirators each year because it is uneconomical. The same can be said for Self-Contained Breathing Apparatus. This is an extremely expensive PPE and again it would be uneconomical to buy each year. When the HAZMAT CTAT does a total phase analysis or LCC analysis for a chemical or process, it calculates as if the user will buy expensive equipment each year. During the a LCC analysis, the PPE cost may be overestimated for some situations.

Sensitivity Analysis Results

Sensitivity analysis is an important part in any analysis because it allows an analyst to see which factors of a particular model are the most influential. Sargent referred to it as finding the key factors inherent to a model. This allows the analyst to get more insight into the model. On p.27 of the User's Guide, the ten most influential factors of the HAZMAT CTAT model are listed. The list shown on p.27 in the User's Guide are the results from a sensitivity analysis conducted by the model developers at TASC. The goal of this sensitivity analysis is to determine which factors are the most influential in the HAZMAT CTAT and then to compare the results with the list shown in the user's guide. Table 4.28 shows the original values along with the range the values were changed. The ranges shown in Table 4.28 were discussed with Dr. Long so that inappropriate ranges would not be used for the sensitivity analysis.

Table 4.28 Sensitivity analysis inputs

	Low	Original	High
Ave # of subsystems	18	36	54
Ave hourly wage	39.41	78.62	117.93
# of PPE workers	462.5	925	1387.5
Time worn factor	0.125	0.25	0.375
Time lost factor	0.04	0.08	0.12
# physical exams	462.5	925	1387.5
Exam cost	427	854	1281
Exam duration	3	6	9
PPE usage	.5	1.00	1.50
Resp. Maintenance Factor	1.4	2.8	4.2

Shown below in Figure 4.14 is the value tornado diagram depicting the ten most influential factors according to DPL based on the inputs from Table 4.28. The most influential factor is located at the top of the diagram. The results from the tornado diagram using DPL produce a slightly different rank order compared to the results from the HAZMAT CTAT's User's Guide. Table 4.29 below depicts how the factors from the two analyses compared to each other. The list from the HAZMAT CTAT user guide is shown on the right side of the table and results from DPL sensitivity analysis is shown on the left side of the table. The blanks on the table indicate that those particular factors did not make the top ten in either the HAZMAT or DPL sensitivity analysis.

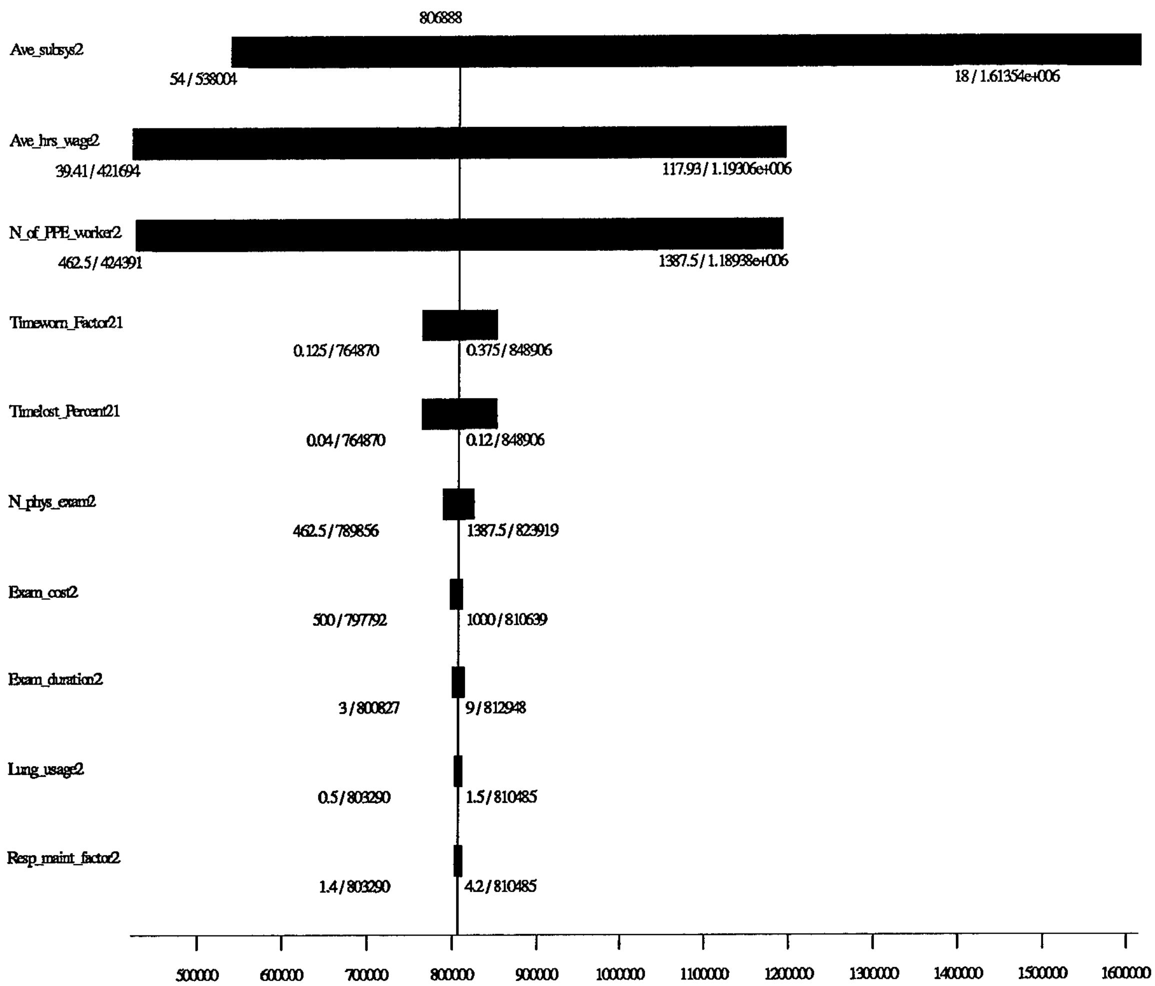


Figure 4.14 DPL sensitivity analysis results

The results from both sensitivity analysis shown in Table 4.29 compare favorably overall, but there are a few problems. Eight out of the ten most influential factors from the DPL sensitivity analysis are in the ten most influential presented in the HAZMAT CTAT user's guide. Although the eight factors in both lists do not match in terms of order of rank, the fact that eight are common to both lists is a positive sign.

One of the factors deviating from the list, however, is the number one factor from the DPL analysis. The fact that the number one factor is absent from the HAZMAT

CTAT's list is troubling. The DPL model calculated that the Average Number of Subsystems is the most influential factor in the HAZMAT CTAT model. The Average Number of Subsystems is used in many of the cost algorithms and the final cost is based on a per subsystem cost.

Table 4.29 Comparison of Rankings of the Sensitivity Analysis Results

List of Influential Factors	HAZMAT	DPL
1. Average Hourly Wage	1	2
2. Average Number of Subsystems		1
3. Number of Workers Using PPE	2	3
4. PPE Time Worn Factor	3	4
5. PPE Time Lost Factor	4	5
6. Number of Workers Requiring Physicals	5	6
7. Physical Exam Cost	6	7
8. PPE Usage	7	9
9. PPE Respiratory Maintenance Factor	8	10
10. PPE Cost	9	11
11. Dispensing and Tracking Factor	10	12
12. Exam Duration		8

This difference in the sensitivity analysis was discussed with the model developer, Dr. John Long. He stated that the Average Number of Subsystems was not considered in their sensitivity analysis because they assumed that the Average Number of Subsystems would be constant. This means that if the Average Number of Subsystems is removed from the DPL list, nine out of ten factors would consistent for both lists. The DT factor is the only factor in the HAZMAT CTAT not in the DPL list, but the DT factor is number 11 in the DPL list if the Average Number of Subsystems is removed from the DPL list.

The goal of the sensitivity analysis was to determine the most influential factors using the DPL model and to determine if they were identical with the list from the HAZMAT CTAT user's guide. The data in Table 4.29 suggest that there are some minor discrepancies with the sensitivity analysis results, but overall, the results are similar.

V. Conclusion

Chapter Overview

This chapter presents a summary of the computer model evaluation, conclusions concerning the use of the HAZMAT CTAT in the Air Force, recommendations concerning improvements to the HAZMAT CTAT, limitations to the study, and recommendations for future research.

Summary

The HAZMAT CTAT is a tool developed by the Air Force in an effort to capture environmental cost associated with the hazardous materials during the life of a weapon system. This thesis concentrated on independently evaluating the HAZMAT CTAT. The computer model evaluation of the HAZMAT CTAT used a methodology suggested by Sargent which included computer model verification, operational validation, conceptual model validity, and sensitivity analysis. The goal of the computer model verification was to determine if the HAZMAT CTAT performed as intended by the model developers. This was done by reprogramming the critical elements of the HAZMAT CTAT into DPL to see if the outputs were identical using the same default values. Some of the problems incurred during the verification include:

1. The Equipment Cost Individual algorithm on p.74 of the User's Guide had a multiplication and addition sign side by side.

2. The terms Air Environmental and Air Cost are mislabeled on p. 84 of the User's Guide

3. The term Time Lost is missing a summation sign on p.74 of the User's Guide.

Although these few problems caused confusion in the initial modeling of the HAZMAT CTAT into DPL, Tables 4.2-4.4 in chapter four illustrates that the outputs from both models were identical once the identified problems were corrected, thus verifying the HAZMAT CTAT.

The goal of the operational validation was to determine if the HAZMAT CTAT cost output for hazardous materials resembles historical hazardous material cost data. The historical data for this comparison came from the MDA C-17 manufacturing process. The criteria for the operational validity was set by Ms. Betty West. The criteria was that the data from the HAZMAT CTAT could not deviate more than ± 25% from the historical data for at least seven of the eight chemicals. The results of the operational validity using the default values in the HAZMAT CTAT are shown in Tables 4.5-4.12 in Chapter Four. The results indicate that the HAZMAT CTAT output for total cost is significantly different than the historical data. Only two of the eight were within the required ± 25% and the range of the deviation for the chemicals that were not within the criteria was 196% to 24205%. The HAZMAT CTAT did not meet the criteria set by Ms. Betty West.

In the conceptual model validity, the assumptions and theories in the HAZMAT CTAT that could have caused the HAZMAT CTAT to fail the operational validity were identified as:

1). The accuracy of the default values

2). User knowledge and model flexibility

3). Extrapolation method

4). The lack of specific values for different sub-processes.

The accuracy of default values was checked by modifying the TW, TL, and DT parameters in the PPE cost category and it indicated that the HAZMAT CTAT may be overestimating the indirect effects of PPE. The assumption of user knowledge and model flexibility may be responsible for inaccurate cost data since the HAZMAT CTAT does not provide directions on properly changing the default values. The assumption of extrapolation may be producing inaccurate cost data because using surface area to extrapolate from one weapon system to another may produce misleading data in some scenarios. The lack of specific default values for different sub-processes can produce erroneous output because the default values should not be same for every process. The default values should reflect the specific nature of each sub-process.

The goal of the sensitivity analysis was to determine which factors were the most influential factors in the HAZMAT CTAT and then to see if the DPL sensitivity analysis results matched the results conducted by the model developers. The comparison of the results from both sensitivity analyses are shown in Table 4.29. The results suggest that both analyses identified similar factors that were the most influential in the model. Eight of ten factors identified in the HAZMAT CTAT User's Guide were also identified by the DPL.

Conclusion

The goal of this research was to answer the research questions presented in Chapter One. By answering the research questions, a determination can be made on the implementation of the HAZMAT CTAT in the acquisition process. Although the results from the verification suggest that the HAZMAT CTAT is implemented correctly, the results from the operational validation and conceptual model validity suggest that the HAZMAT CTAT may need more research before implementation into the Air Force weapon system acquisition process. Supporting the need for more research on the HAZMAT CTAT are the results from the operational validity.

Tables 4.5-4.12 illustrate that the HAZMAT CTAT and MDA data had large percentage differences for total cost. Only chemicals 3 and 6 were within the required ± 25%. This standard was set by Ms. Betty West, the HAZMAT CTAT program manager, Human Systems Center, Brooks AFB. The range of percentage differences for total cost between the HAZMAT CTAT and MDA data were from 19% to 24205%. This large range of values suggest that there could be a problem with the HAZMAT CTAT's ability to predict real-world data or it could mean that MDA has difficulty in calculating costs associated with hazardous materials. The average percentage difference for total cost between the two data sets was 4049% and the average actual difference was $105,575. Given these results, the HAZMAT CTAT needs more studies to be conducted on the operational validity, so a proper model can be implemented.

There were two trends that were identified during the operational validation of the HAZMAT CTAT and these trends may mean that the HAZMAT CTAT may have a threshold in when it can be used. The trends were as the percentage differences for total cost decreased, the number of people and cost per year increased. These trends may suggest that the HAZMAT CTAT may be more suitable for larger processes. Also certain assumptions inherent in the HAZMAT CTAT were identified as a potential cause for the large differences in the operational validation. These assumptions should be studied or corrected to improve the validity of the HAZMAT. Some improvements are necessary for the HAZMAT CTAT to be an effective tool, but it is a good start in the right direction by the management at Brooks AFB in trying to capture environmental LCC of hazardous materials.

Recommendations on Improving the HAZMAT CTAT

1. Concentrate on the Main Cost Drivers

Currently, the HAZMAT CTAT consists of twelve cost categories to calculate the environmental cost of hazardous materials in the manufacturing, O&S, and disposal phases in the life of a weapon system. Although the inclusion of the twelve cost categories seem logical in calculating environmental cost, the majority of the environmental cost is primarily influenced on a few cost categories. PPE, medical, and potential legal liability constitute the bulk of the cost associated with hazardous materials. This model should concentrate on the accuracy of these cost drivers before concentrating on other cost categories. Dr. Long, the developer of the HAZMAT CTAT, stated that the factors associated with PPE have high uncertainty. The TL and TW factors were pointed out as being two of most influential factors in the model yet had the most uncertainty in the model. This is counter intuitive. One would surmise that if certain factors caused great deal of sensitivity to the model, one would want to assure the accuracy of those factors. Rather than accepting the high uncertainty, the accuracy of these factors should have been investigated further since the cost associated with PPE is the main cost driver according to the model.

Recommendation: To concentrate on the accuracy of the main cost drivers, since they constitute the majority of the environmental costs. The accuracy of the main cost drivers is vital to the accuracy of the HAZMAT CTAT

2. Verify and Validate the Extrapolation Theory

The HAZMAT CTAT currently uses the surface area of the airplane to extrapolate environmental cost for different airplanes. For the cargo airplane category, the default values were calculated using data from the C-130 aircraft. This data is used to estimate cost for all the cargo airplanes. The HAZMAT CTAT differentiates the many types of aircraft by using the surface area of the aircraft. Essentially, the C-130 data is extrapolated to estimate the cost of other airplanes. This might be a realistic approach to estimate costs for different airplanes, but the problem lies in the fact that this extrapolation theory has never been tested by an independent source to decide if it is proper for the HAZMAT CTAT. Until this assumption is tested, the accuracy of estimates for airplanes will be questioned.

Recommendation: Verify and validate the extrapolation method based upon surface area using more historical data (e.g. C-141).

3. Improve the Representativeness of the Data

The HAZMAT CTAT's foundation for the default values is based on one system for each of the categories. As stated before, the cargo aircraft default values are based on data gathered from the C-130. The C-130 data is used represent all the other cargo aircraft in the inventory. The cargo aircraft category is even more limited because the C-130 was also limited in process data information. Since the data from the C-130 was so limited, this limitation directly effects all cargo aircraft. The accuracy of the HAZMAT CTAT is in question because the data seems to lack true representation of that category. Recommendation: To alleviate this limitation, data should be gathered from multiple airplanes in each category to get more representative data for each category.

4. User Usability

The original version of the HAZMAT CTAT was a DOS run program and, within the last year, was changed to a Windows driven program. This changed occurred to accommodate customers who felt the DOS version was not user friendly. Although the HAZMAT CTAT is more user friendly, this does not mean the HAZMAT CTAT is user usable. The user usability problems stem from a lack of explanation of the default values and a lack of direction on properly changing the default values. For example, the default value for the Dispensing and Tracking factor for cargo aircraft is .86. What does .86 mean? Would a person using the HAZMAT CTAT know that their specific situation requires a factor of .7? Without proper direction and an explanation of these baseline values, the user would be unable to make accurate changes to meet their specific situation.

Recommendation: Provide an explanation of the default values. More importantly, develop a methodology to provide direction on how to change the default values properly. This direction will be better if the user is not required to spend numerous hours gathering data to make the appropriate changes. This will increase user usability of the HAZMAT CTAT and will improve the accuracy of the projected costs.

5. Implement Stochastic or Probabilistic Methodology

Currently, the HAZMAT CTAT is a purely deterministic model using algorithms to calculate environmental LCC. Consideration should be given to adding some stochasticity to some of the cost categories in the model since the very nature of the environmental arena is stochastic. Since the HAZMAT CTAT is concerned about the LCC of hazardous materials, it needs to recognize that changes will occur during that life cycle. For example, if the HAZMAT CTAT was used presently to get the an estimate on the LCC of hexavalent chromium, there is a high probability that this analysis would be erroneous. Within the next few years, there is speculation that hexavalent chromium will be tightly regulated by the EPA. The HAZMAT CTAT should try to account for some of this speculation, especially in the potential legal liability cost category.

Recommendation: Try to incorporate probabilities into the HAZMAT CTAT, particularly in the potential legal liability cost category. A possible methodology for getting probabilities can be from doing a statistical analysis on all the chemicals associated with Superfund sites. By statistically evaluating the chemicals associated with Superfund sites, probabilities for potential legal liabilities for hazardous materials may be developed.

6. HAZMAT CTAT Maintenance

As mentioned earlier, the environmental arena is very dynamic. Due to the very nature of the environmental field, the HAZMAT CTAT should be maintained and modified to reflect the constant changes. Currently, there is no contract with the originators of the model to modify the HAZMAT CTAT as regulations and directives change.

Recommendation: Develop a maintainability plan to ensure that the HAZMAT CTAT is reviewed every several years and that modifications be made to reflect the current environmental state .

7. Modify the HAZMAT CTAT to Identify the Different Types of Costs in Cost Trade-off Analysis

The HAZMAT currently incorporates the direct and indirect costs associated with hazardous materials in one cost. Since some indirect costs may never really be realized, these cost should be separated into different categories so that a decision-maker understands which costs are direct and which costs indirect. This allows the decision-maker to weigh the two types of costs before rendering a decision. For example, consider a situation where a chemical has a low direct cost and a high indirect costs and a replacement chemical has a high direct cost and low indirect cost. If all the costs are grouped into one category, the decision-maker never knows that there was a large disparity between direct and indirect cost for the two chemicals. By showing the different types of cost used in the analysis, decision-maker is allowed to make a more informative decision.

Recommendation: Modify the HAZMAT CTAT to present the direct and indirect cost of using hazardous materials so that user can make a more informative decision.

Limitations to this Study

The limitations of this study are primarily due to the limited availability of weapon system environmental cost data and time constraints. The limitations of this study are the following:

1. As stated before, the C-17 was chosen for this study because the Air Force has a current contract with MDA studying hazardous material environmental LCC, but due to time constraints, data on only eight chemicals could be gathered. A sample size of eight chemicals for the C-17 is a limitation of the study because a such a small sample is not a good representation of all the hazardous material environmental cost and thus reduces the power of the results from the analysis. The way to increase power is to increase the sample size (Law and Kelton, 1982). A sample size of eight yields a low level of power.

2. The HAZMAT CTAT has a database for numerous weapon systems, ranging from Army tanks to Air Force aircraft. The fact that data for only one weapon system was tested is a limitation of this study because it is hard to generalize about the validity of model by testing just one component of the model. More than one component of the model should be tested to reflect the general accuracy of the HAZMAT CTAT.

3. This study only concentrated on the cost-per-year-per-subsystem and not on the LCC of hazardous materials. This study only looked at the cost for a hazardous material for one year rather than looking at the cost of hazardous materials for several years. Since

the HAZMAT CTAT has been marketed as a LCC tool for hazardous materials, a LCC analysis would have been appropriate. A LCC analysis was infeasible due to a lack of data on environmental costs. By only looking at the cost of hazardous materials for just one year, the LCC ability of the HAZMAT CTAT was not tested. This is a limitation to this study.

Future Research Topics

There are many potential future research topics that would supplement the work in this thesis. Potential research topics are discussed below.

A validation study on other weapon systems in the HAZMAT CTAT would be a good supplement to this thesis. The HAZMAT CTAT consists of a database with a wide range of weapon systems. The database ranges from tanks to helicopters to fighter aircraft. A limitation identified in this research is that only one component was tested. If environmental cost data becomes available on other weapon systems, it can be used to test the operational validity of the HAZMAT CTAT in those other weapon systems.

A study researching the effects of wearing personal protection equipment during work in a manufacturing plant would enhance the accuracy of the default values inherent in the HAZMAT CTAT. This research can concentrate on the degradation of work and the time lost associated with wearing PPE on the job. My research pointed out that the degradation of PPE is highly uncertain in the model due to lack of studies on this topic. This type of research would help clarify the uncertainty associated with the degradation of work while wearing PPE and would help the modelers of the HAZMAT CTAT in accurately modeling the indirect effects of the PPE.

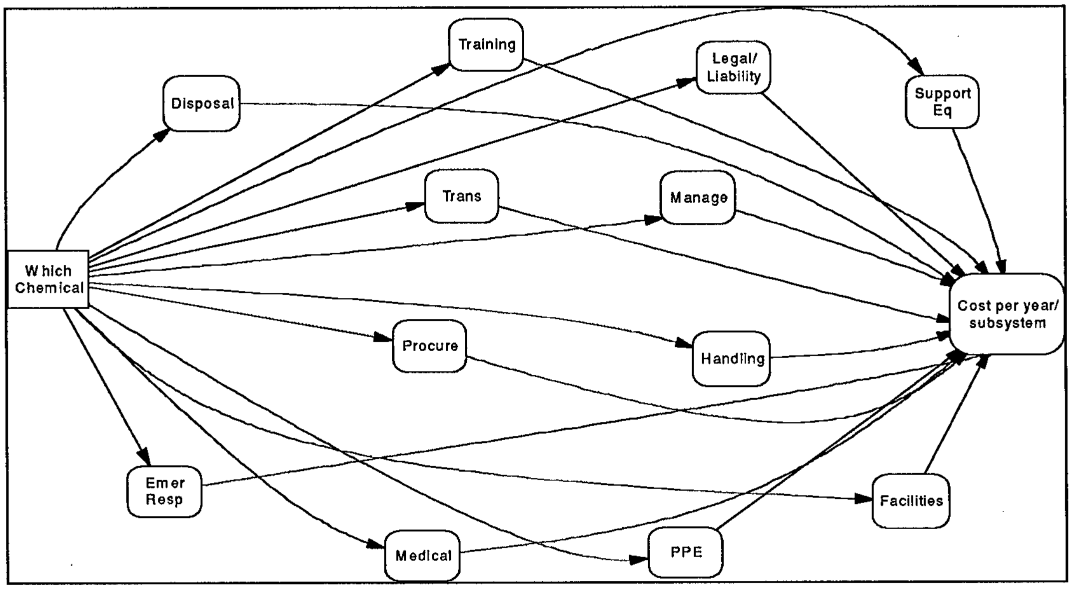
A study concentrating on modifying the HAZMAT CTAT so that the HAZMAT CTAT could handle stochastic nature of the environmental arena would enhance the current HAZMAT CTAT. Most people will agree the environmental arena is stochastic in nature. Currently, the HAZMAT CTAT is deterministic and can not handle some of the dynamic features implicit in the environmental arena. During the verification of the HAZMAT CTAT, DPL was used to replicate the HAZMAT CTAT. DPL has the ability to perform calculations with distributions and probabilities. Research needs to be done to properly modify the current DPL model to perform some stochastic calculations reflecting the changing nature of the environment..

A study to test the extrapolation theory of the HAZMAT CTAT would be helpful to the developers of the model since this theory has never been tested. Currently, the HAZMAT CTAT uses the surface area of the aircraft to extrapolate the cost from one aircraft to another. It was pointed out in the Conceptual Model Validity section, that the C-130 was used to calculate values for all cargo aircraft and that the surface area was used to account for the different cost of different cargo aircraft. This assumption needs to be tested to determine if this type the extrapolation using the surface area ratio is accurate in the HAZMAT CTAT.

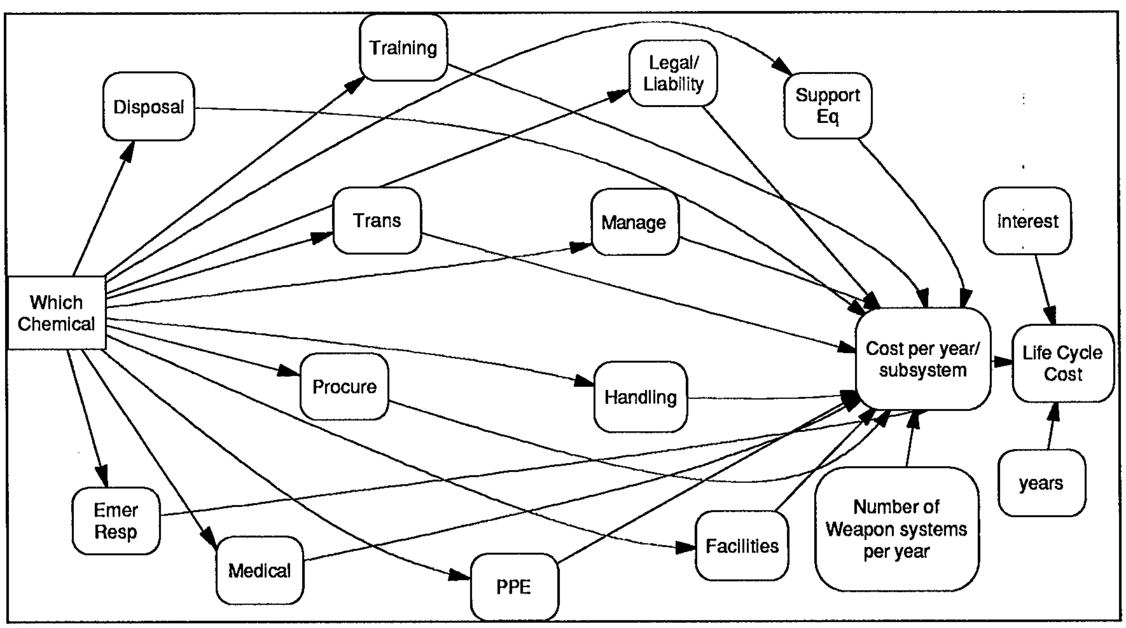
A validation study on the operational and support phase of a weapon system would be vital to the HAZMAT CTAT since most of the environmental costs are spent in the phase. As stated before, most of the environmental cost for a weapon system in incurred in the operational and support phase (Blanchard, 1995). This study was limited to the manufacturing phase for cargo aircraft. The accuracy of the HAZMAT CTAT in the O&S phase would be important to the overall evaluation of the HAZMAT CTAT.

Appendix A: Influence Diagrams and Value Nodes used for Computer Model Verification

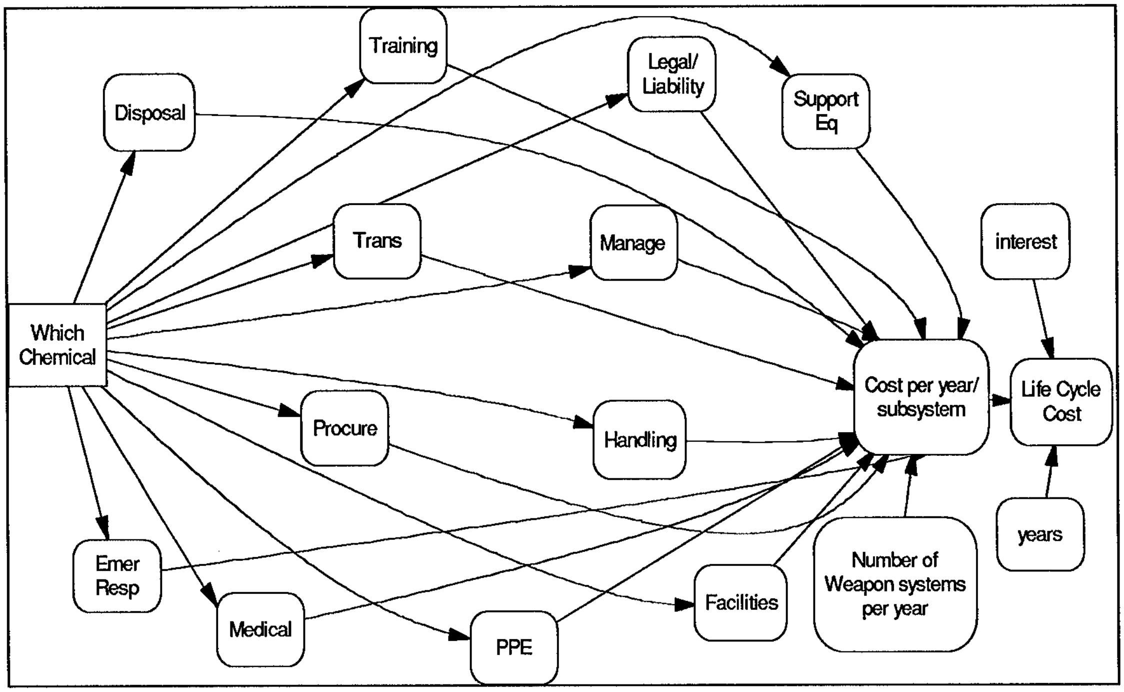
Manufacturing Cost-Per-Year-Per-Subsystem



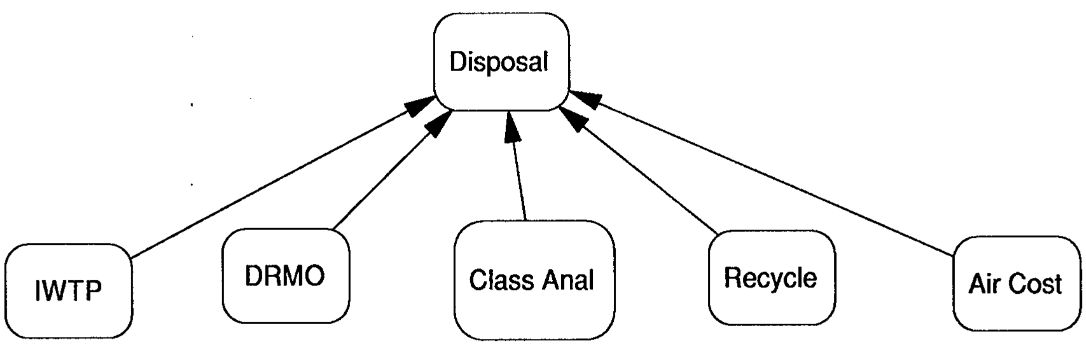
Mamufacturing Total Phase Cost-Per-Subsystem



Operational and Support Total Phase Cost-Per-Subsystem



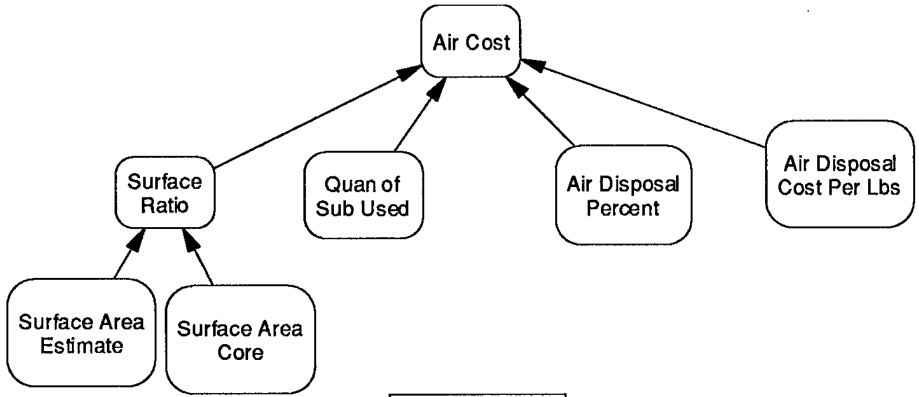
Disposal Value Node



Cost Algorithm

Disposal = IWTP+DRMO+Class Anal+Recycle+Air Cost

Disposal Value Node (Cont): Air Cost Node

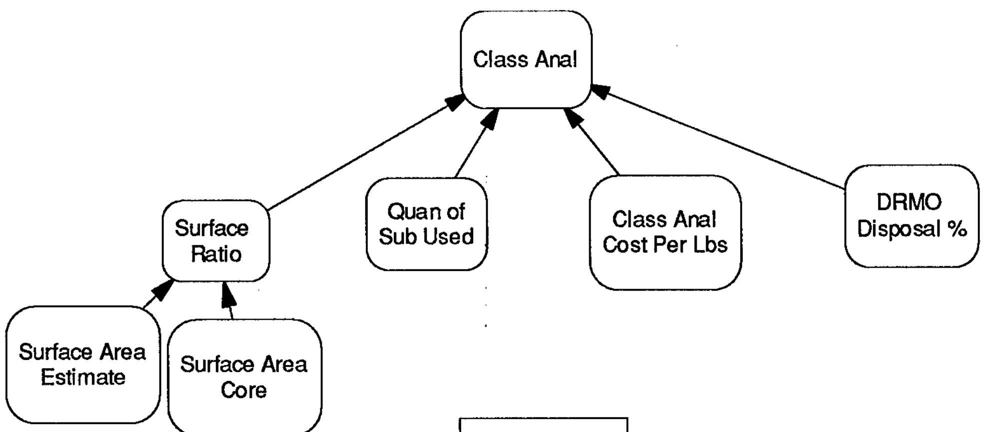


Cost Algorithms

Air Cost = Surface Ratio*Quantity Substance Used*Air Disposal Percent*Air Disposal Cost

Surface Ratio = Surface Area Estimate/Surface Area Core

Disposal Value Node (Cont): Classification and Analysis Node

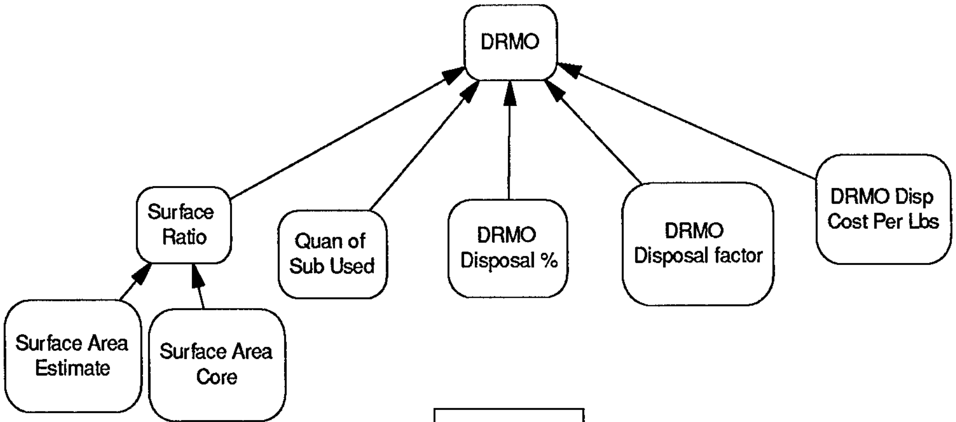


Cost Algorithm

Class Analysis = Surface Ratio*Quantity Substance Used*Class Analysis Cost

Surface Ratio = Surface Area Estimate/Surface Area Core

Disposal Value Node (Cont): DRMO Node

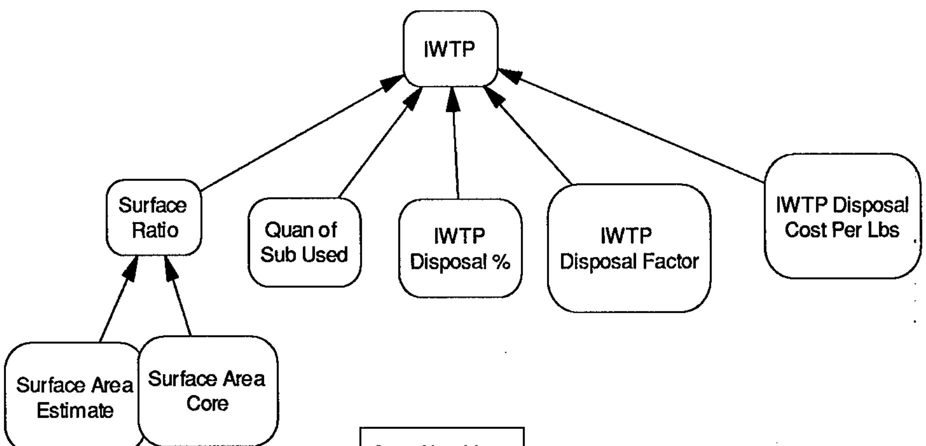


Cost Algorithm

DRMO = Surface Ratio*Quantity Substance Used*DRMO Disposal Percent*DRMO Disposal Factor*DRMO Disposal Cost

Surface Ratio = Surface Area Estimate/Surface Area Core

Disposal Value Node (Cont): IWTP Node

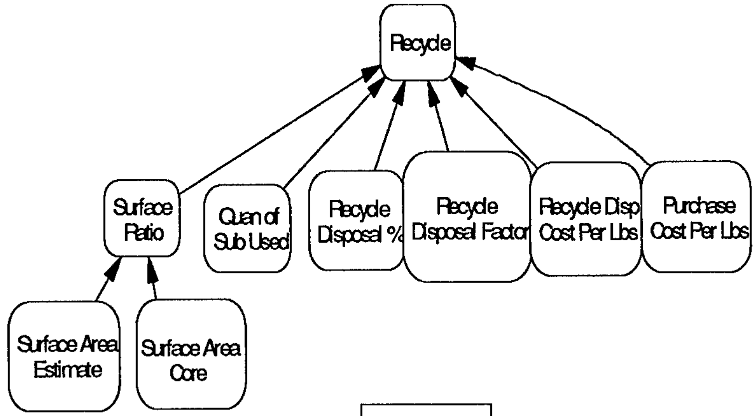


Cost Algorithms

IWTP = Surface Ratio*Quantity Substance Used*IWTP Disposal Percent*IWTP Disposal Factor*IWTP Disposal Cost

Surface Ratio = Surface Area Estimate/Surface Area Core

Disposal Value Node (Cont): Recycle Node

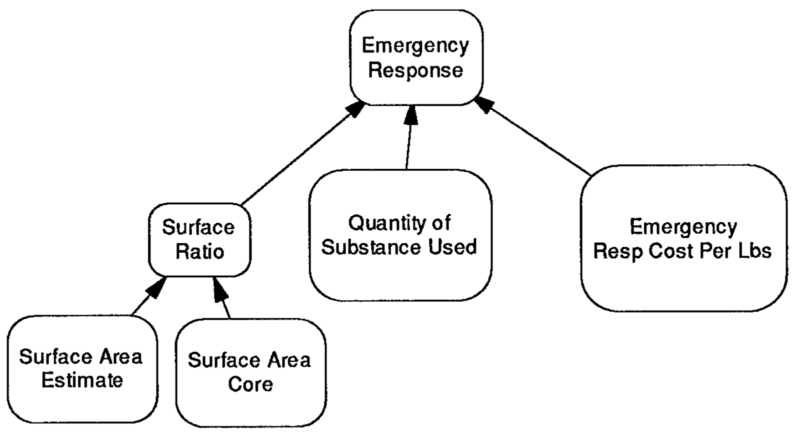


Cost Algorithms

Recycle = Surface Ratio*Quantity Substance Used*Recycle Disposal Percent*Recycle Disposal Factor*(Recycle Disposal Cost-Purchase Cost)

Surface Ratio = Surface Area Estimate/ Surface Area

Emergency Response Value Node

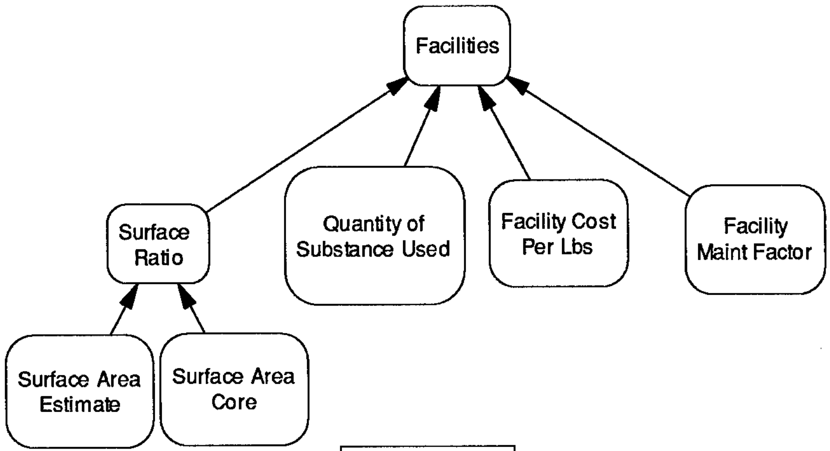


Cost Algorithms

Emergency Response = Surface Ratio*Quantity Substance Used*Emerg Respon Cost

Surface Ratio = Surface Area Estimate/Surface Area Core

Facility Value Node

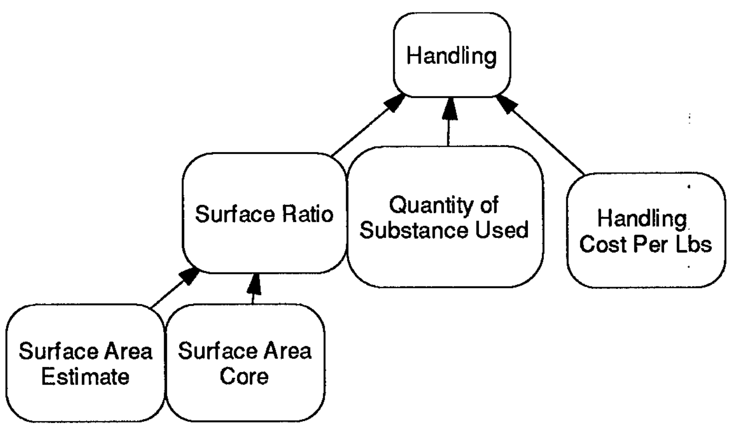


Cost Algorithms

Facilities = (Surface Ratio* Quantity Substance Used*Facility Cost)*(1+Facility Maint Factor)

Surface Ratio = Surface Area Estimate/Surface Area Core

Handling Value Node

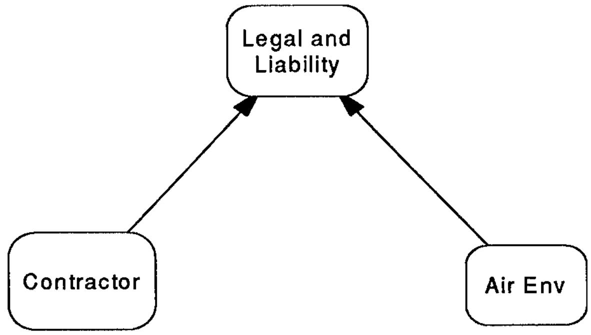


Cost Algorithms

Handling = Surface Ratio x Quantity Substance Used x HandlingCost Factor

Surface Ratio = Surface Area Estimate/Surface Area Core

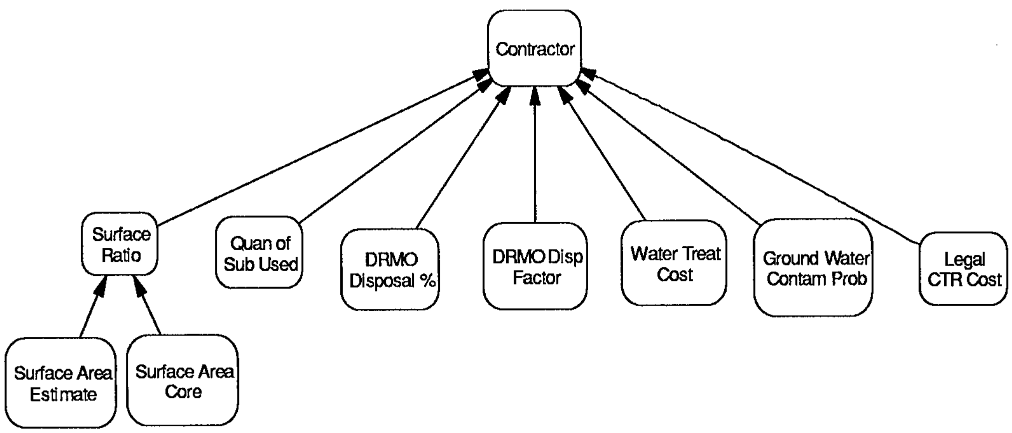
Potential Legal/Liability Value Node



Cost Algorithms

Legal/Liability = Contractor + Air Env

Potential Legal/Liability Value Node (Cont): Contract Value Node

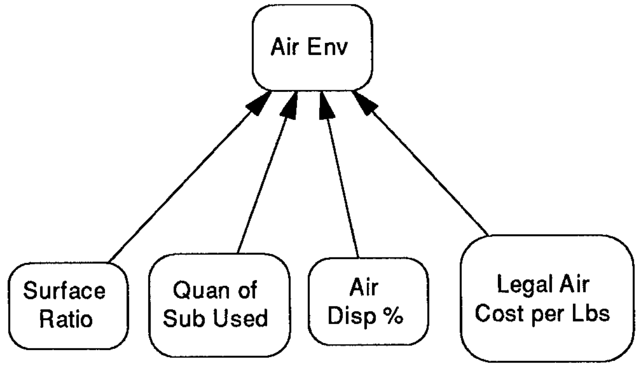


Cost Algorithms

Contractor = SRatio*Quan Substance Used*DRMO Disposal %*DRMO Disposal Factor*(Legal CTR Cost+(Ground Water Contam Prob*Water Treat cost))

SRatio = Surface Area Estimate/Surface Area

Potential Legal/Liability Value Node (Cont): Air Environmental Value Node

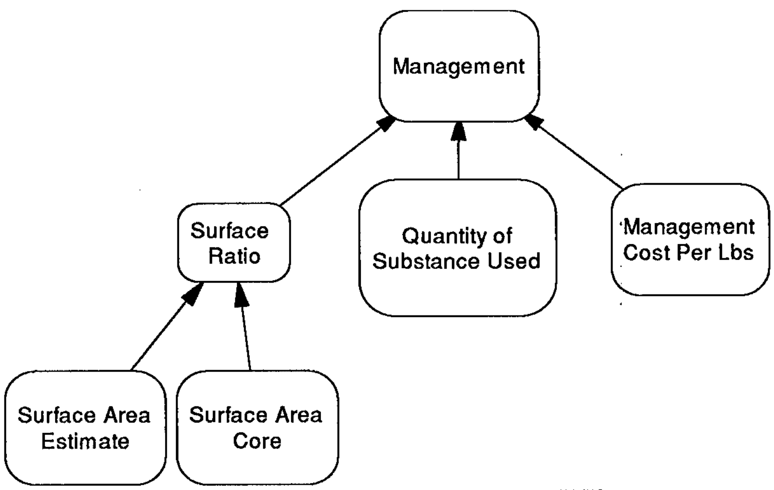


Cost Algorithms

Air Env = Surface Ratio*Quantity Substance Used*Air Disposal %*Legal Air Cost

Surface Ratio = Surface Area Estimate/Surface Area Core

Management Value Node

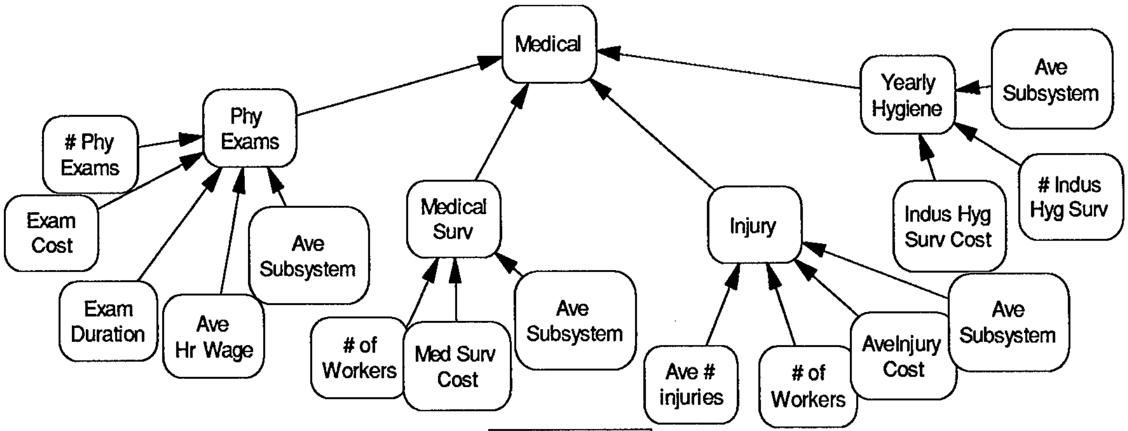


Cost Algorithm

Management = Surface Ratio*Quantity Substance Used*ManageCost

Surface Ratio = Surface Area Estimate/Surface Area Core

Medical Value Node



Cost Algorithms

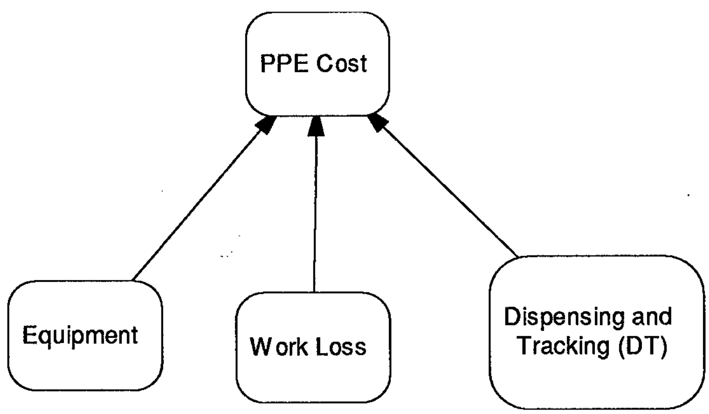
Medical = Phy Exam+Medical Surv+Injury+Yearly Hygiene

Phy Exams = (# Physical Exams*(Exam Cost+(Exam Duration*Ave Hourly Wage)))/Ave Subsystems

Medical Surv = (# of Workers*Medical Surv Cost)/ Ave Subsystems

Injury = (Ave # Injuries*Ave Injury Cost*# of Workers)/Ave Subsystems

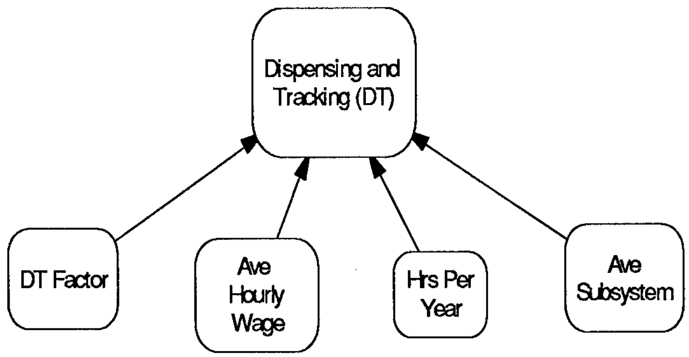
Personal Protection Equipment Value Node



Cost Algorithms

PPE = Equip+Work loss+Dispensing and Tracking (DT)

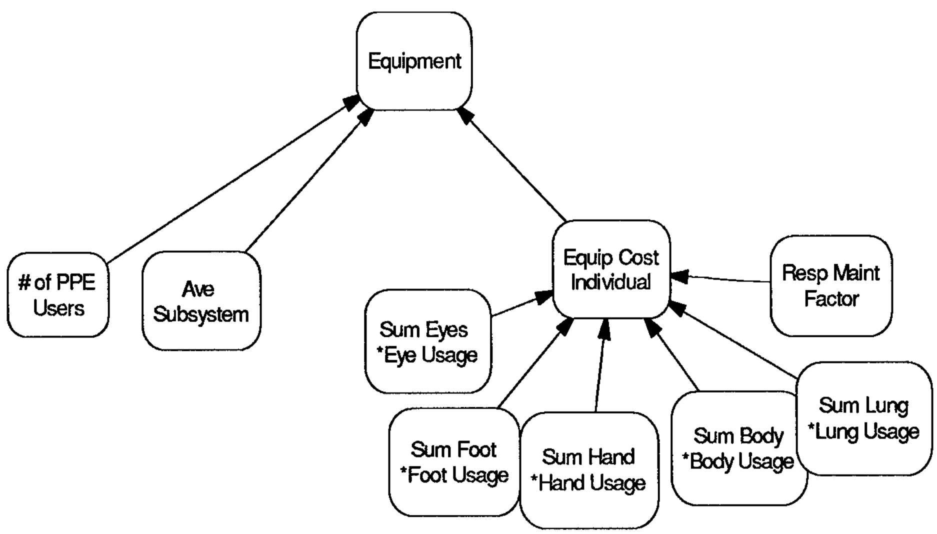
Personal Protection Equipment Value Node (Cont): DT Value Node



Cost Algorithms

Dispensing and Tracking = (Dispensing Tracking Factor*Ave Hourly Wage*Hours Per Year)/ Ave Subsystems

Personal Protection Equipment Value Node (Cont): Equipment Value Node

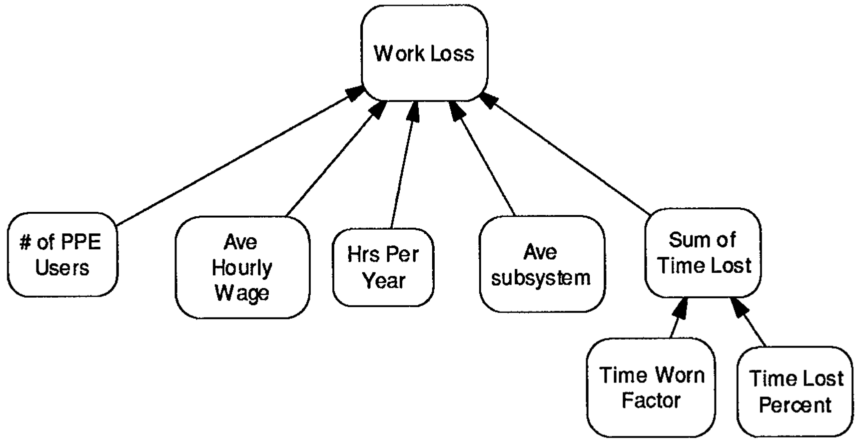


Cost Algorithms

Equip = (# PPE Workers*Equip Cost Individual)/ Ave Subsystems

Eq Cost Ind = (Eye Cost*Eye Usage)+(Foot Cost*Foot Usage)+(Hand Cost*Hand Usage)+(Body Cost*Body Usage)+(Lung Cost*Lung Usage*Resp Maint Fac)

Personal Protection Equipment Value Node (Cont): Work Loss Value Node

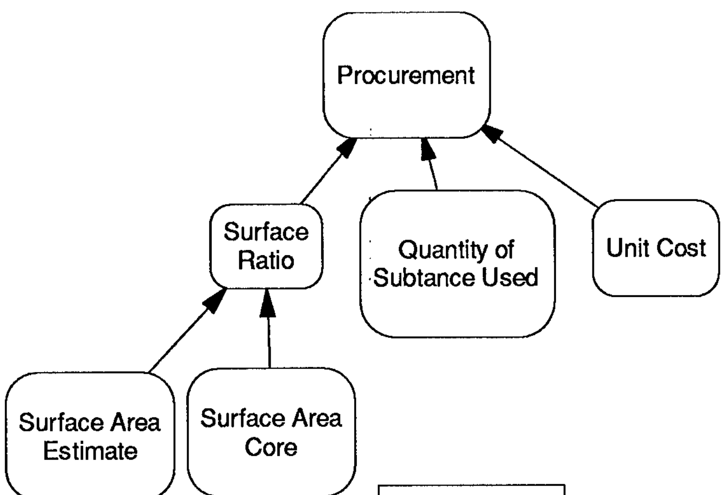


Cost Algorithms

Work Loss = (# PPE Users*Ave Hourly Wage*Hours Per Year*Sum of Time Lost)/Ave Subsystems

Sum of Time Lost = Sum of (Time Worn Factor*Time Lost Percent)

Procurement Value Node

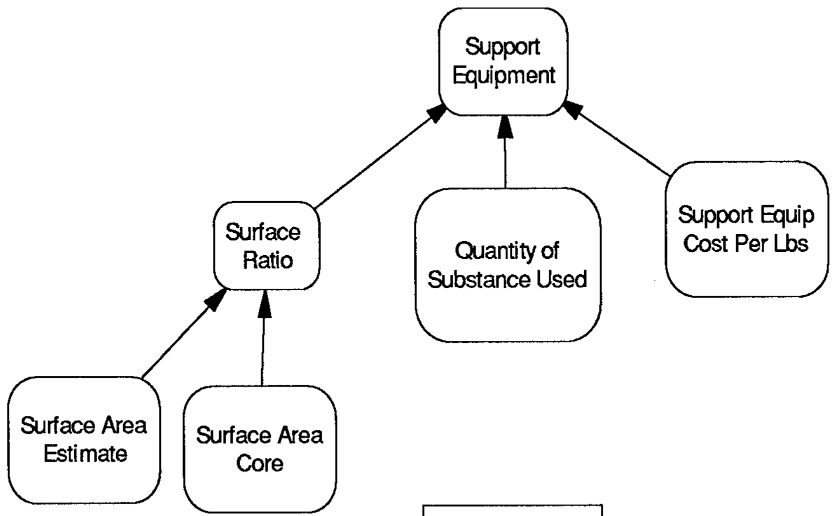


Cost Algorithm

Procurement = Surface Ratio*Quantity Substance Used*Unit Cost

Surface Ratio = Surface Area Estimate/Surface Area Core

Support Equipment Value Node

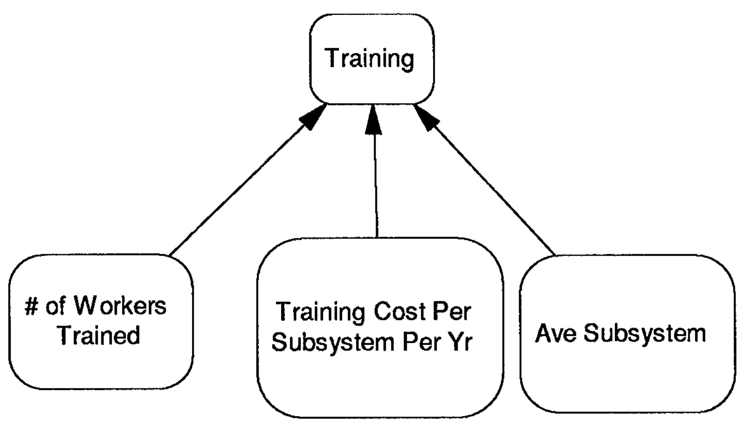


Cost Algorithms

Support Equipment = Surface Ratio*Quantity Substance Used*Supp Equip Cost

Surface Ratio = Surface Area Estimate/Surface Area Core

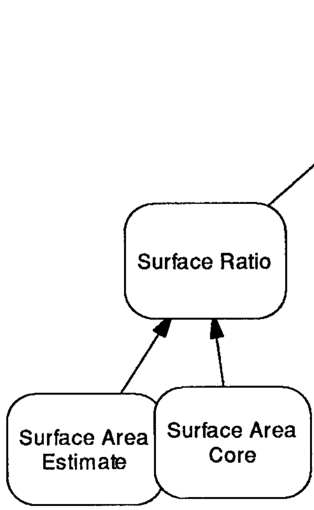
Training Value Node



Cost Algorithm

Training = (# of Workers Trained*Training Cost)/Ave Subsystems

Transportation Value Node



Cost Algorithm

Transportation = Surface Ratio*Quantity Substance Used*TransCost

Surface Ratio = Surface Area Estimate/Surface Area Core

Appendix B: HAZMAT CTAT Verification Parameters and Results

Verification #1: Manufacturing Cost-Per-Year-Per-Subsystem

Chemical #1:
Estimate Base Year: 1993
Input Base Year: 1993
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Year/Subsystem
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 36
Surface Area of Subsystem: 7590
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 36

Number of Workers in Process: 925
Average Hourly Wage: 78.62
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .773
Facility Maintenance Factor: .1
Handling Cost per Pound: 2.659
Management Cost per Pound: .983
Number of Workers Requiring Physical: 925
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: .11
Average Cost per Injury: 500
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 250
Number of Workers using PPE: 925
Dispensing and Tracking Factor: .86
Contractor Disposed Waste Liability Cost per Pound: 7.012
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .020
Support Equipment Cost per Pound: .027
Number of Workers Requiring Training: 925
Training Cost per Worker: 88.24
Transportation Cost per Pound: 1.276

Chemical Name: Preimpreg Glass Fabrication Epoxy
Substance ID Number: 080281527
Quantity Used: 10 Pounds
Unit Of Issue: Pounds
Unit Cost: 9.07
Air / Environmental Contractor Disposal Percent: 72%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 18%
DRMO Cost per Pound: .2
DRMO Factor: 1
IWTP Percent: 0%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 10%
PPE Eye (Chem Resistant Safety Goggles) Cost: 8.00
PPE Eye (Chem Resistant Safety Goggles) Usage: 1
PPE Eye (Chem Resistant Safety Goggles) Time Lost: 1%
PPE Eye (Chem Resistant Safety Goggles) Time Worn: 100%
PPE Hand (Seamless Natural Rubber Gloves) Cost: .20
PPE Hand (Seamless Natural Rubber Gloves) Usage: 250
PPE Hand (Seamless Natural Rubber Gloves) Time Lost: 8%
PPE Hand (Seamless Natural Rubber Gloves) Time Worn: 25%
Physical Exam Cost: 854
Physical Exam Duration: 6 hours

Results (Thousands of Dollars)

Disposal : 0
Emergency Response: 0
Facilities: .01
Handling: .03
Management: .01
Medical: 35.48
PPE: 131.45
Potential Liability: .01
Procurement: .09
Support Equipment: 0
Training: 2.27
Transportation: .01

Total Cost: 169.36

Chemical #2:
Estimate Base Year: 1993
Input Base Year: 1993
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Year/Subsystem
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 36
Surface Area of Subsystem: 7590
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 36

Number of Workers in Process: 925
Average Hourly Wage: 78.62
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .773
Facility Maintenance Factor: .1
Handling Cost per Pound: 2.659
Management Cost per Pound: .983
Number of Workers Requiring Physical: 925
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: .11
Average Cost per Injury: 500
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 250
Number of Workers using PPE: 925
Dispensing and Tracking Factor: .86
Contractor Disposed Waste Liability Cost per Pound: 7.012
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .020
Support Equipment Cost per Pound: .027
Number of Workers Requiring Training: 925
Training Cost per Worker: 88.24
Transportation Cost per Pound: 1.276
Chemical Name: Preimpreg Glass Fabrication Phenolic
Substance ID Number: 080281552
Quantity Used: 10 Pounds

Unit Of Issue: Pounds
Unit Cost: 14.06
Air / Environmental Contractor Disposal Percent: 15%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 45%
DRMO Cost per Pound: .3
DRMO Factor: 1
IWTP Percent: 0%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 40%
PPE Eye (Wilson Spectra Safety Glassses) Cost: 7.40
PPE Eye (Chem Resistant Safety Goggles) Usage: 1
PPE Eye (Chem Resistant Safety Goggles) Time Lost: 1%
PPE Eye (Chem Resistant Safety Goggles) Time Worn: 100%
PPE Hand (Seamless Natural Rubber Gloves) Cost: .20
PPE Hand (Seamless Natural Rubber Gloves) Usage: 250
PPE Hand (Seamless Natural Rubber Gloves) Time Lost: 8%
PPE Hand (Seamless Natural Rubber Gloves) Time Worn: 25%
Physical Exam Cost: 854
Physical Exam Duration: 6 hours

Results (Thousands of Dollars)

Disposal : 0
Emergency Response: 0
Facilities: .01
Handling: .03
Management: .01
Medical: 35.48
PPE: 131.44
Potential Liability: .04
Procurement: .14
Support Equipment: 0
Training: 2.27
Transportation: .01

Total Cost: 169.43

Chemical #3:
Estimate Base Year: 1993
Input Base Year: 1993
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Year/Subsystem
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 36
Surface Area of Subsystem: 7590
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 36

Number of Workers in Process: 925
Average Hourly Wage: 78.62
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .773
Facility Maintenance Factor: .1
Handling Cost per Pound: 2.659
Management Cost per Pound: .983
Number of Workers Requiring Physical: 925
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: .11
Average Cost per Injury: 500
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 250
Number of Workers using PPE: 925
Dispensing and Tracking Factor: .86
Contractor Disposed Waste Liability Cost per Pound: 7.012
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .020
Support Equipment Cost per Pound: .027
Number of Workers Requiring Training: 925
Training Cost per Worker: 88.24
Transportation Cost per Pound: 1.276
Chemical Name: Primer Zinc Chromate
Substance ID Number: 081011000
Quantity Used: 6 Gallons

Unit Of Issue: Gallons
Unit Cost: 11.68
Air / Environmental Contractor Disposal Percent: 15%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 45%
DRMO Cost per Pound: .2
DRMO Factor: 1
IWTP Percent: 0%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 40%
PPE Foot (Tyvek Disposal Elastic Top Boots) Cost: .46
PPE Eye (Tyvek Disposal Elastic Top Boots) Usage: 250
PPE Eye (Tyvek Disposal Elastic Top Boots) Time Lost: 5%
PPE Eye (Tyvek Disposal Elastic Top Boots) Time Worn: 100%
PPE Hand (Neoprene Gloves) Cost: 3.80
PPE Hand (Neoprene Gloves) Usage: 12
PPE Hand (Neoprene Gloves) Time Lost: 9%
PPE Hand (Neoprene Gloves) Time Worn: 25%
Physical Exam Cost: 854
Physical Exam Duration: 6 hours

Results (Thousands of Dollars)

Disposal : 0.3
Emergency Response: 0
Facilities: .04
Handling: .13
Management: .05
Medical: 35.48
PPE: 312.48
Potential Liability: .18
Procurement: .07
Support Equipment: 0
Training: 2.27
Transportation: .06

Total Cost: 350.97

Verification #2: Manufacturing Total Phase Cost-Per-Subsystem

Chemical #1:
Estimate Base Year: 1993
Input Base Year: 1993
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Total Phase Cost
Number of Years: 4 years
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 9
Surface Area of Subsystem: 7590
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 9

Number of Workers in Process: 925
Average Hourly Wage: 78.62
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .773
Facility Maintenance Factor: .1
Handling Cost per Pound: 2.659
Management Cost per Pound: .983
Number of Workers Requiring Physical: 925
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: .11
Average Cost per Injury: 500
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 250
Number of Workers using PPE: 925
Dispensing and Tracking Factor: .86
Contractor Disposed Waste Liability Cost per Pound: 7.012
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .020
Support Equipment Cost per Pound: .027
Number of Workers Requiring Training: 925
Training Cost per Worker: 88.24
Transportation Cost per Pound: 1.276
Chemical Name: Preimpreg Glass Fabrication Epoxy

Substance ID Number: 080281527
Quantity Used: 10 Pounds
Unit Of Issue: Pounds
Unit Cost: 9.07
Air / Environmental Contractor Disposal Percent: 72%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 18%
DRMO Cost per Pound: .2
DRMO Factor: 1
IWTP Percent: 0%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 10%
PPE Eye (Chem Resistant Safety Goggles) Cost: 8.00
PPE Eye (Chem Resistant Safety Goggles) Usage: 1
PPE Eye (Chem Resistant Safety Goggles) Time Lost: 1%
PPE Eye (Chem Resistant Safety Goggles) Time Worn: 100%
PPE Hand (Seamless Natural Rubber Gloves) Cost: .20
PPE Hand (Seamless Natural Rubber Gloves) Usage: 250
PPE Hand (Seamless Natural Rubber Gloves) Time Lost: 8%
PPE Hand (Seamless Natural Rubber Gloves) Time Worn: 25%
Physical Exam Cost: 854
Physical Exam Duration: 6 hours

Results (Thousands of Dollars)

Disposal : 0
Emergency Response: 0
Facilities: .27
Handling: .83
Management: .31
Medical: 4454.17
PPE: 16500.6
Potential Liability: .46
Procurement: 2.84
Support Equipment: 0
Training: 284.6
Transportation: .39

Total Cost: 21244.48

Chemical #2:
Estimate Base Year: 1993
Input Base Year: 1993
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Total Phase Cost
Number of Years: 4
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 9
Surface Area of Subsystem: 7590
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 9

Number of Workers in Process: 925
Average Hourly Wage: 78.62
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .773
Facility Maintenance Factor: .1
Handling Cost per Pound: 2.659
Management Cost per Pound: .983
Number of Workers Requiring Physical: 925
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: .11
Average Cost per Injury: 500
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 250
Number of Workers using PPE: 925
Dispensing and Tracking Factor: .86
Contractor Disposed Waste Liability Cost per Pound: 7.012
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .020
Support Equipment Cost per Pound: .027
Number of Workers Requiring Training: 925
Training Cost per Worker: 88.24
Transportation Cost per Pound: 1.276
Chemical Name: Preimpreg Glass Fabrication Phenolic
Substance ID Number: 080281552
Quantity Used: 10 Pounds

Unit Of Issue: Pounds
Unit Cost: 14.06
Air / Environmental Contractor Disposal Percent: 15%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 45%
DRMO Cost per Pound: .3
DRMO Factor: 1
IWTP Percent: 0%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 40%
PPE Eye (Wilson Spectra Safety Glassses) Cost: 7.40
PPE Eye (Chem Resistant Safety Goggles) Usage: 1
PPE Eye (Chem Resistant Safety Goggles) Time Lost: 1%
PPE Eye (Chem Resistant Safety Goggles) Time Worn: 100%
PPE Hand (Seamless Natural Rubber Gloves) Cost: .20
PPE Hand (Seamless Natural Rubber Gloves) Usage: 250
PPE Hand (Seamless Natural Rubber Gloves) Time Lost: 8%
PPE Hand (Seamless Natural Rubber Gloves) Time Worn: 25%
Physical Exam Cost: 854
Physical Exam Duration: 6 hours

Results (Thousands of Dollars)

Disposal : .04
Emergency Response: 0
Facilities: .27
Handling: .84
Management: .31
Medical: 4454.17
PPE: 16498.66
Potential Liability: 1.15
Procurement: 4.42
Support Equipment: 0
Training: 284.6
Transportation: .39

Total Cost: 21244.85

Chemical #3:
Estimate Base Year: 1993
Input Base Year: 1993
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Total Phase Cost
Number of Years: 4
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 9
Surface Area of Subsystem: 7590
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 9

Number of Workers in Process: 925
Average Hourly Wage: 78.62
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .773
Facility Maintenance Factor: .1
Handling Cost per Pound: 2.659
Management Cost per Pound: .983
Number of Workers Requiring Physical: 925
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: .11
Average Cost per Injury: 500
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 250
Number of Workers using PPE: 925
Dispensing and Tracking Factor: .86
Contractor Disposed Waste Liability Cost per Pound: 7.012
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .020
Support Equipment Cost per Pound: .027
Number of Workers Requiring Training: 925
Training Cost per Worker: 88.24
Transportation Cost per Pound: 1.276
Chemical Name: Primer Zinc Chromate
Substance ID Number: 081011000
Quantity Used: 6 Gallons

Unit Of Issue: Gallons
Unit Cost: 11.68
Air / Environmental Contractor Disposal Percent: 15%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 45%
DRMO Cost per Pound: .2
DRMO Factor: 1
IWTP Percent: 0%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 40%
PPE Foot (Tyvek Disposal Elastic Top Boots) Cost: .46
PPE Eye (Tyvek Disposal Elastic Top Boots) Usage: 250
PPE Eye (Tyvek Disposal Elastic Top Boots) Time Lost: 5%
PPE Eye (Tyvek Disposal Elastic Top Boots) Time Worn: 100%
PPE Hand (Neoprene Gloves) Cost: 3.80
PPE Hand (Neoprene Gloves) Usage: 12
PPE Hand (Neoprene Gloves) Time Lost: 9%
PPE Hand (Neoprene Gloves) Time Worn: 25%
Physical Exam Cost: 854
Physical Exam Duration: 6 hours

Results (Thousands of Dollars)

Disposal : 0.92
Emergency Response: 0
Facilities: 1.28
Handling: 4.00
Management: 1.48
Medical: 4454.17
PPE: 39247.63
Potential Liability: 5.49
Procurement: 2.19
Support Equipment: 0
Training: 284.6
Transportation: 1.92

Total Cost: 44003.72

Verification #3: Operational and Support Total Phase Cost-Per-Subsystem

Chemical #1:
Estimate Base Year: 1993
Input Base Year: 1993
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Total Phase Cost
Number of Years: 5 years
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystem per System: 1
Number of Systems in O&S: 15
Number of Operating Locations: 1
Program Maintenance Schedule: 1
Economic Life of Subsystem: 15
Surface Area of Subsystem: 7590
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Operations and Support

Number of Workers in Process: 235
Average Hourly Wage: 12.38
Operation and Support Type: Depot
Disposal Contractor Analysis/ Classification Cost per Pound: .567
Emergency Response Cost per Pound: 0
Facility Cost per Pound: 0
Facility Maintenance Factor: .1
Handling Cost per Pound: 0.8
Management Cost per Pound: 2.084
Number of Workers Requiring Physical: 235
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: .089
Average Cost per Injury: 2822
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 1318
Number of Workers using PPE: 235
Dispensing and Tracking Factor: 1.40
Contractor Disposed Waste Liability Cost per Pound: 7.012
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .020
Support Equipment Cost per Pound: 0

Number of Workers Requiring Training: 235
Training Cost per Worker: 0
Transportation Cost per Pound: 0
Chemical Name: Corrosion Preventive Compound
Substance ID Number: 002312354
Quantity Used: 3 Pounds
Unit Of Issue: 5 Pounds
Unit Cost: 13.73
Air / Environmental Contractor Disposal Percent: 15%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 45%
DRMO Cost per Pound: .2
DRMO Factor: 1
IWTP Percent: 0%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 40%
PPE Eye (Futura Goggles) Cost: 8.20
PPE Eye (Futura Goggles) Usage: 1
PPE Eye (Futura Goggles) Time Lost: 1%
PPE Eye (Futura Goggles) Time Worn: 100%
PPE Hand (Seamless Natural Rubber Gloves) Cost: .20
PPE Hand (Seamless Natural Rubber Gloves) Usage: 250
PPE Hand (Seamless Natural Rubber Gloves) Time Lost: 8%
PPE Hand (Seamless Natural Rubber Gloves) Time Worn: 25%
Physical Exam Cost: 854
Physical Exam Duration: 6 hours

Results (Thousands of Dollars)

Disposal : .62
Emergency Response: 0
Facilities: 0
Handling: .04
Management: 1.48
Medical: 881.92
PPE: 732.38
Potential Liability: 2.6
Procurement: 1.94
Support Equipment: 0
Training: 0
Transportation: 0

Total Cost: 1620.98

Chemical #2:
Estimate Base Year: 1993
Input Base Year: 1993
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Total Phase Cost
Number of Years: 5 years
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystem per System: 1
Number of Systems in O&S: 15
Number of Operating Locations: 1
Program Maintenance Schedule: 1
Economic Life of Subsystem: 15
Surface Area of Subsystem: 7590
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Operations and Support

Number of Workers in Process: 235
Average Hourly Wage: 12.38
Operation and Support Type: Depot
Disposal Contractor Analysis/ Classification Cost per Pound: .567
Emergency Response Cost per Pound: 0
Facility Cost per Pound: 0
Facility Maintenance Factor: .1
Handling Cost per Pound: 0.8
Management Cost per Pound: 2.084
Number of Workers Requiring Physical: 235
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: .089
Average Cost per Injury: 2822
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 1318
Number of Workers using PPE: 235
Dispensing and Tracking Factor: 1.40
Contractor Disposed Waste Liability Cost per Pound: 7.012
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .020
Support Equipment Cost per Pound: 0
Number of Workers Requiring Training: 235
Training Cost per Worker: 0

Transportation Cost per Pound: 0
Chemical Name: Corrosion Resisting Coating
Substance ID Number: 008113723
Quantity Used: 3 Pounds
Unit Of Issue: 2 Pounds
Unit Cost: 14.64
Air / Environmental Contractor Disposal Percent: 15%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 45%
DRMO Cost per Pound: .2
DRMO Factor: 1
IWTP Percent: 0%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 40%
PPE Body (Neoprene Apron) Cost: 15.8
PPE Body (Neoprene Apron) Usage: 2
PPE Body (Neoprene Apron) Time Lost: 5%
PPE Body (Neoprene Apron) Time Worn: 20%
PPE Eye (Futura Goggles) Cost: 8.20
PPE Eye (Futura Goggles) Usage: 1
PPE Eye (Futura Goggles) Time Lost: 1%
PPE Eye (Futura Goggles) Time Worn: 100%
PPE Hand (Seamless Natural Rubber Gloves) Cost: .20
PPE Hand (Seamless Natural Rubber Gloves) Usage: 250
PPE Hand (Seamless Natural Rubber Gloves) Time Lost: 8%
PPE Hand (Seamless Natural Rubber Gloves) Time Worn: 25%
Physical Exam Cost: 132
Physical Exam Duration: 8 hours

Results (Thousands of Dollars)

Disposal : .24
Emergency Response: 0
Facilities: 0
Handling: .01
Management: .6
Medical: 363.04
PPE: 947.53
Potential Liability: 1.04
Procurement: 2.08
Support Equipment: 0
Training: 0
Transportation: 0

Total Cost: 1314.54

Chemical #3:
Estimate Base Year: 1993
Input Base Year: 1993
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Total Phase Cost
Number of Years: 5 years
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystem per System: 1
Number of Systems in O&S: 15
Number of Operating Locations: 1
Program Maintenance Schedule: 1
Economic Life of Subsystem: 15
Surface Area of Subsystem: 7590
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Operations and Support

Number of Workers in Process: 235
Average Hourly Wage: 12.38
Operation and Support Type: Depot
Disposal Contractor Analysis/ Classification Cost per Pound: .567
Emergency Response Cost per Pound: 0
Facility Cost per Pound: 0
Facility Maintenance Factor: .1
Handling Cost per Pound: 0.8
Management Cost per Pound: 2.084
Number of Workers Requiring Physical: 235
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: .089
Average Cost per Injury: 2822
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 1318
Number of Workers using PPE: 235
Dispensing and Tracking Factor: 1.40
Contractor Disposed Waste Liability Cost per Pound: 7.012
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .020
Support Equipment Cost per Pound: 0
Number of Workers Requiring Training: 235
Training Cost per Worker: 0

Transportation Cost per Pound: 0
Chemical Name: Hydraulic Fluid
Substance ID Number: 001594472
Quantity Used: 11
Unit of Issue: 16 oz
Unit Cost: 14.64
Air / Environmental Contractor Disposal Percent: 1%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 84%
DRMO Cost per Pound: .6
DRMO Factor: 1
IWTP Percent: 0%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 15%
PPE Eye (Chem Resistant Safety Glasses) Cost: 8.00
PPE Eye (Chem Resistant Safety Glasses) Usage: 1
PPE Eye (Chem Resistant Safety Glasses) Time Lost: 1%
PPE Eye (Chem Resistant Safety Glasses) Time Worn: 100%
PPE Hand (Neoprene Gloves) Cost: 3.8
PPE Hand (Neoprene Gloves) Usage: 12
PPE Hand (Neoprene Gloves) Time Lost: 9%
PPE Hand (Neoprene Gloves) Time Worn: 25%
PPE Lung (Organic Vapor Respirator) Cost: 3.48
PPE Lung (Organic Vapor Respirator) Usage: 250
PPE Lung (Organic Vapor Respirator) Time Lost: 10%
PPE Lung (Organic Vapor Respirator) Time Worn: 100%
Respiratory Maintenance Factor: 0
Physical Exam Cost: 77
Physical Exam Duration: 1.75 hours

Results (Thousands of Dollars)

Disposal : .51
Emergency Response: 0
Facilities: 0
Handling: .04
Management: 1.08
Medical: 264.52
PPE: 2693.24
Potential Liability: 3.55
Procurement: 1.83
Support Equipment: 0
Training: 0
Transportation: 0

Total Cost: 2964.77

Appendix C: MDA Cost Data (Dollars)

Chemical #1:

PROCUREMENT: 500
HANDLING: 0
TRAINING: 0
PROTECTION EQUIPMENT
EQUIPMENT: 521
WORK LOSS: 0
DISPENSING & TRACKING: 130
MEDICAL
OCCUPATIONAL PHYSICAL EXAMS: 3,507
INJURY / ILLNESS: 0
INDUSTRIAL HYGIENE SURVEYS: 6,000
DISPOSAL
MATERIAL DISPOSAL: 2
RECYCLING: 0
LEGAL LIABILITY
DISPOSAL LIABILITY: 0
EMISSIONS LIABILITY: 13

TOTAL COST: 10,673
TOTAL COST/YEAR/SUBSYSTEM: 1,334

Chemical #2:

PROCUREMENT: 3,455
HANDLING: 0
TRAINING: 0
PROTECTION EQUIPMENT
EQUIPMENT: 50
WORK LOSS: 216
DISPENSING & TRACKING: 12
MEDICAL
OCCUPATIONAL PHYSICAL EXAMS: 334
INJURY / ILLNESS: 0
INDUSTRIAL HYGIENE SURVEYS: 0
DISPOSAL
MATERIAL DISPOSAL: 229
RECYCLING: 0
LEGAL LIABILITY
DISPOSAL LIABILITY: 0
EMISSIONS LIABILITY: 58

TOTAL COST: 4,353
TOTAL COST/YEAR/SUBSYSTEM: 544

Chemical #3:

PROCUREMENT: 27,114
HANDLING: 0
TRAINING: 0
PROTECTION EQUIPMENT
EQUIPMENT: 835,900
WORK LOSS: 14,655,680
DISPENSING & TRACKING: 208,975
MEDICAL
OCCUPATIONAL PHYSICAL EXAMS: 1,148,125
INJURY / ILLNESS: 0
INDUSTRIAL HYGIENE SURVEYS: 0
DISPOSAL
MATERIAL DISPOSAL: 11
RECYCLING: 0
LEGAL LIABILITY: 0
DISPOSAL LIABILITY: 0
EMISSIONS LIABILITY: 60

TOTAL COST: 16,875,864
TOTAL COST/YEAR/SUBSYSTEM: 2,109,483

Chemical #4:

PROCUREMENT: 270
HANDLING: 0
TRAINING: 0
PROTECTION EQUIPMENT
EQUIPMENT: 121
WORK LOSS: 135
DISPENSING & TRACKING: 30
MEDICAL
OCCUPATIONAL PHYSICAL EXAMS: 8,016
INJURY / ILLNESS: 0
INDUSTRIAL HYGIENE SURVEYS: 100
DISPOSAL
MATERIAL DISPOSAL: 0
RECYCLING: 0
LEGAL LIABILITY: 0
DISPOSAL LIABILITY: 0
EMISSIONS LIABILITY: 4

TOTAL COST: 8,677
TOTAL COST/YEAR/SUBSYSTEM: 1085

Chemical #5:

PROCUREMENT: 551
HANDLING: 0
TRAINING: 0
PROTECTION EQUIPMENT
EQUIPMENT: 141
WORK LOSS: 0
DISPENSING & TRACKING: 35
MEDICAL
OCCUPATIONAL PHYSICAL EXAMS: 32,231
INJURY / ILLNESS: 0
INDUSTRIAL HYGIENE SURVEYS: 0
DISPOSAL
MATERIAL DISPOSAL: 0
RECYCLING: 0
LEGAL LIABILITY: 0
DISPOSAL LIABILITY: 0
EMISSIONS LIABILITY: 28

TOTAL COST: 32,987
TOTAL COST/YEAR/SUBSYSTEM: 4,123

Chemical #6:

PROCUREMENT: 998,584
HANDLING: 0
TRAINING: 0
PROTECTION EQUIPMENT
EQUIPMENT: 863,135
WORK LOSS: 14,655,680
DISPENSING & TRACKING: 215,784
MEDICAL
OCCUPATIONAL PHYSICAL EXAMS: 1,148,125
INJURY / ILLNESS: 0
INDUSTRIAL HYGIENE SURVEYS: 500
DISPOSAL
MATERIAL DISPOSAL: 3,452
RECYCLING: 0
LEGAL LIABILITY: 0
DISPOSAL LIABILITY: 0
EMISSIONS LIABILITY: 596

TOTAL COST: 17,885,855
TOTAL COST/YEAR/SUBSYSTEM: 2,235,732

Chemical #7:

PROCUREMENT: 134
HANDLING: 0
TRAINING: 0
PROTECTION EQUIPMENT
EQUIPMENT: 123
WORK LOSS: 2163
DISPENSING & TRACKING: 31
MEDICAL
OCCUPATIONAL PHYSICAL EXAMS: 167
INJURY / ILLNESS: 0
INDUSTRIAL HYGIENE SURVEYS: 50
DISPOSAL
MATERIAL DISPOSAL: 1
RECYCLING: 0
LEGAL LIABILITY: 0
DISPOSAL LIABILITY: 0
EMISSIONS LIABILITY: 3

TOTAL COST: 2,671
TOTAL COST/YEAR/SUBSYSTEM: 334

Chemical #8:

PROCUREMENT: 430
HANDLING: 0
TRAINING: 0
PROTECTION EQUIPMENT
EQUIPMENT: 496
WORK LOSS: 0
DISPENSING & TRACKING: 124
MEDICAL
OCCUPATIONAL PHYSICAL EXAMS: 3,340
INJURY / ILLNESS: 0
INDUSTRIAL HYGIENE SURVEYS: 0
DISPOSAL
MATERIAL DISPOSAL: 0
RECYCLING: 4
LEGAL LIABILITY: 0
DISPOSAL LIABILITY: 0
EMISSIONS LIABILITY: 0

TOTAL COST: 4,395
TOTAL COST/YEAR/SUBSYSTEM: 549

Appendix D: HAZMAT CTAT Validation Parameters and Results

Validation #1: Manufacturing Cost-Per-Year-Per-Subsystem

Chemical #1:
Estimate Base Year: 1996
Input Base Year: 1996
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Year/Subsystem
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 8
Surface Area of Subsystem: 22371
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 8

Number of Workers in Process: 21
Average Hourly Wage: 40
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .829
Facility Maintenance Factor: .1
Handling Cost per Pound: 2.850
Management Cost per Pound: 1.054
Number of Workers Requiring Physical: 21
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: 0
Average Cost per Injury: 536
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 268
Number of Workers using PPE: 21
Dispensing and Tracking Factor: .86
Contractor Disposed Waste Liability Cost per Pound: 7.517
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .021
Support Equipment Cost per Pound: .029
Number of Workers Requiring Training: 21
Training Cost per Worker: 80.00
Transportation Cost per Pound: 1.368

Chemical Name: 1,1,1 Trichloroethane
Substance ID Number: 005511487
Quantity Used: .09
Unit Of Issue: 55 Gallons
Unit Cost: 560.55
Air / Environmental Contractor Disposal Percent: 73%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 15%
DRMO Cost per Pound: 1.072
DRMO Factor: 1
IWTP Percent: 2%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 10%
PPE Eye (Futura Goggles) Cost: 8.79
PPE Eye (Futura Goggles) Usage: 1
PPE Eye (Futura Goggles) Time Lost: 1%
PPE Eye (Futura Goggles) Time Worn: 100%
PPE Hand (Neoprene Gloves) Cost: 4.07
PPE Hand (Neoprene Gloves) Usage: 12
PPE Hand (Neoprene Gloves) Time Lost: 9%
PPE Hand (Neoprene Gloves) Time Worn: 25%
Physical Exam Cost: 115.99
Physical Exam Duration: 1 hours

Results (Thousands of Dollars)

Disposal : .04
Emergency Response: 0
Facilities: .11
Handling: .33
Management: .12
Medical: .44
PPE: 16.19
Potential Liability: .15
Procurement: .15
Support Equipment: 0
Training: .21
Transportation: .16

Total Cost: 17.9

Chemical #1 w/ Modified Values:
Estimate Base Year: 1996
Input Base Year: 1996
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Year/Subsystem
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 8
Surface Area of Subsystem: 22371
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 8

Number of Workers in Process: 21
Average Hourly Wage: 40
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .829
Facility Maintenance Factor: .1
Handling Cost per Pound: 2.850
Management Cost per Pound: 1.054
Number of Workers Requiring Physical: 21
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: 0
Average Cost per Injury: 536
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 268
Number of Workers using PPE: 21
Dispensing and Tracking Factor: .2
Contractor Disposed Waste Liability Cost per Pound: 7.517
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .021
Support Equipment Cost per Pound: .029
Number of Workers Requiring Training: 21
Training Cost per Worker: 80.00
Transportation Cost per Pound: 1.368
Chemical Name: 1,1,1 Trichloroethane
Substance ID Number: 005511487
Quantity Used: .09
Unit Of Issue: 55 Gallons

Unit Cost: 560.55
Air / Environmental Contractor Disposal Percent: 73%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 15%
DRMO Cost per Pound: 1.072
DRMO Factor: 1
IWTP Percent: 2%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 10%
PPE Eye (Futura Goggles) Cost: 8.79
PPE Eye (Futura Goggles) Usage: 1
PPE Eye (Futura Goggles) Time Lost: 0%
PPE Eye (Futura Goggles) Time Worn: 100%
PPE Hand (Neoprene Gloves) Cost: 4.07
PPE Hand (Neoprene Gloves) Usage: 12
PPE Hand (Neoprene Gloves) Time Lost: 0%
PPE Hand (Neoprene Gloves) Time Worn: 25%
Physical Exam Cost: 115.99
Physical Exam Duration: 1 hours

Results (Thousands of Dollars)

Disposal : .04
Emergency Response: 0
Facilities: .11
Handling: .33
Management: .12
Medical: .44
PPE: 2.23
Potential Liability: .15
Procurement: .15
Support Equipment: 0
Training: .21
Transportation: .16

Total Cost: 3.94

Chemical #2:
Estimate Base Year: 1996
Input Base Year: 1996
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Year/Subsystem
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 8
Surface Area of Subsystem: 22371
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 8

Number of Workers in Process: 2
Average Hourly Wage: 40
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .829
Facility Maintenance Factor: .1
Handling Cost per Pound: 2.850
Management Cost per Pound: 1.054
Number of Workers Requiring Physical: 2
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: 0
Average Cost per Injury: 536
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 268
Number of Workers using PPE: 21
Dispensing and Tracking Factor: .86
Contractor Disposed Waste Liability Cost per Pound: 7.517
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .021
Support Equipment Cost per Pound: .029
Number of Workers Requiring Training: 2
Training Cost per Worker: 80.00
Transportation Cost per Pound: 1.368
Chemical Name: 1,1,1 Trichloroethane
Substance ID Number: 005511487
Quantity Used: 35.8
Unit Of Issue: Gallons

Unit Cost: 1.62
Air / Environmental Contractor Disposal Percent: 73%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 15%
DRMO Cost per Pound: 1.072
DRMO Factor: 1
IWTP Percent: 2%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 10%
PPE Eye (Splash Guard Chem Goggles) Cost: 8.74
PPE Eye (Splash Guard Chem Goggles) Usage: 1
PPE Eye (Splash Guard Chem Goggles) Time Lost: 1%
PPE Eye (Splash Guard Chem Goggles) Time Worn: 100%
PPE Hand (Neoprene Gloves) Cost: 4.07
PPE Hand (Neoprene Gloves) Usage: 12
PPE Hand (Neoprene Gloves) Time Lost: 9%
PPE Hand (Neoprene Gloves) Time Worn: 25%
Physical Exam Cost: 115.99
Physical Exam Duration: 1 hours

Results (Thousands of Dollars)

Disposal : .32
Emergency Response: 0
Facilities: .77
Handling: 2.41
Management: .89
Medical: .07
PPE: 9.63
Potential Liability: 1.10
Procurement: .17
Support Equipment: .02
Training: .02
Transportation: 1.15

Total Cost: 16.55

Chemical #2 w/ Modified Values:
Estimate Base Year: 1996
Input Base Year: 1996
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Year/Subsystem
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 8
Surface Area of Subsystem: 22371
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 8

Number of Workers in Process: 2
Average Hourly Wage: 40
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .829
Facility Maintenance Factor: .1
Handling Cost per Pound: 0
Management Cost per Pound: .054
Number of Workers Requiring Physical: 2
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: 0
Average Cost per Injury: 536
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 268
Number of Workers using PPE: 2
Dispensing and Tracking Factor: .2
Contractor Disposed Waste Liability Cost per Pound: 2.517
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .021
Support Equipment Cost per Pound: .029
Number of Workers Requiring Training: 21
Training Cost per Worker: 80.00
Transportation Cost per Pound: .2
Chemical Name: 1,1,1 Trichloroethane
Substance ID Number: 005511487
Quantity Used: 35.8
Unit Of Issue: Gallons

Unit Cost: 1.62
Air / Environmental Contractor Disposal Percent: 73%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 15%
DRMO Cost per Pound: 1.072
DRMO Factor: 1
IWTP Percent: 2%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 10%
PPE Eye (Splash Guard Chem Goggles) Cost: 8.74
PPE Eye (Splash Guard Chem Goggles) Usage: 1
PPE Eye (Splash Guard Chem Goggles) Time Lost: 1%
PPE Eye (Splash Guard Chem Goggles) Time Worn: 100%
PPE Hand (Neoprene Gloves) Cost: 4.07
PPE Hand (Neoprene Gloves) Usage: 12
PPE Hand (Neoprene Gloves) Time Lost: 9%
PPE Hand (Neoprene Gloves) Time Worn: 25%
Physical Exam Cost: 115.99
Physical Exam Duration: 1 hours

Results (Thousands of Dollars)

Disposal : .3
Emergency Response: 0
Facilities: .72
Handling: 0
Management: .43
Medical: .07
PPE: 1.95
Potential Liability: .44
Procurement: .16
Support Equipment: .02
Training: .02
Transportation: .16

Total Cost: 4.27

Chemical #3:
Estimate Base Year: 1996
Input Base Year: 1996
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Year/Subsystem
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 8
Surface Area of Subsystem: 22371
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 8

Number of Workers in Process: 6775
Average Hourly Wage: 40
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .829
Facility Maintenance Factor: .1
Handling Cost per Pound: 2.850
Management Cost per Pound: 1.054
Number of Workers Requiring Physical: 6775
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: 0
Average Cost per Injury: 536
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 268
Number of Workers using PPE: 6775
Dispensing and Tracking Factor: .86
Contractor Disposed Waste Liability Cost per Pound: 7.517
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .021
Support Equipment Cost per Pound: .029
Number of Workers Requiring Training: 21
Training Cost per Worker: 80.00
Transportation Cost per Pound: 1.368
Chemical Name: Primer Sealing Compound
Substance ID Number: 0109335383
Quantity Used: 151.8
Unit Of Issue: Pint

Unit Cost: 23.38
Air / Environmental Contractor Disposal Percent: 2%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 5%
DRMO Cost per Pound: 10.72
DRMO Factor: 1
IWTP Percent: 2%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 93%
PPE Eye (Wilson Spectra Safety Glasses) Cost: 7.93
PPE Eye (Wilson Spectra Safety Glasses) Usage: 1
PPE Eye (Wilson Spectra Safety Glasses) Time Lost: 1%
PPE Eye (Wilson Spectra Safety Glasses) Time Worn: 100%
PPE Hand (Neoprene Gloves) Cost: 4.07
PPE Hand (Neoprene Gloves) Usage: 12
PPE Hand (Neoprene Gloves) Time Lost: 9%
PPE Hand (Neoprene Gloves) Time Worn: 25%
Physical Exam Cost: 115.99
Physical Exam Duration: 1 hours

Results (Thousands of Dollars)

Disposal : .24
Emergency Response: 0
Facilities: .41
Handling: 1.28
Management: .47
Medical: 132.14
PPE: 2347.01
Potential Liability: .19
Procurement: 10.46
Support Equipment: .01
Training: 67.75
Transportation: .61

Total Cost: 2560.57

Chemical #3 w/ Modified Values:
Estimate Base Year: 1996
Input Base Year: 1996
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Year/Subsystem
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 8
Surface Area of Subsystem: 22371
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 8

Number of Workers in Process: 6775
Average Hourly Wage: 40
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .829
Facility Maintenance Factor: .1
Handling Cost per Pound: 2.850
Management Cost per Pound: 1.054
Number of Workers Requiring Physical: 6775
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: 0
Average Cost per Injury: 536
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 268
Number of Workers using PPE: 6775
Dispensing and Tracking Factor: .2
Contractor Disposed Waste Liability Cost per Pound: 7.517
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .021
Support Equipment Cost per Pound: .029
Number of Workers Requiring Training: 21
Training Cost per Worker: 80.00
Transportation Cost per Pound: 1.368
Chemical Name: Primer Sealing Compound
Substance ID Number: 0109335383
Quantity Used: 151.8
Unit Of Issue: Pint

Unit Cost: 23.38
Air / Environmental Contractor Disposal Percent: 2%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 5%
DRMO Cost per Pound: 10.72
DRMO Factor: 1
IWTP Percent: 2%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 93%
PPE Eye (Wilson Spectra Safety Glasses) Cost: 7.93
PPE Eye (Wilson Spectra Safety Glasses) Usage: 1
PPE Eye (Wilson Spectra Safety Glasses) Time Lost: 2%
PPE Eye (Wilson Spectra Safety Glasses) Time Worn: 100%
PPE Hand (Neoprene Gloves) Cost: 4.07
PPE Hand (Neoprene Gloves) Usage: 12
PPE Hand (Neoprene Gloves) Time Lost: 2%
PPE Hand (Neoprene Gloves) Time Worn: 25%
Physical Exam Cost: 115.99
Physical Exam Duration: 1 hours

Results (Thousands of Dollars)

Disposal : .24
Emergency Response: 0
Facilities: .41
Handling: 1.28
Management: .47
Medical: 132.14
PPE: 1811.70
Potential Liability: .19
Procurement: 10.46
Support Equipment: .01
Training: 67.75
Transportation: .61

Total Cost: 1991.39

Chemical #4:
Estimate Base Year: 1996
Input Base Year: 1996
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Year/Subsystem
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 8
Surface Area of Subsystem: 22371
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 8

Number of Workers in Process: 48
Average Hourly Wage: 40
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .889
Facility Maintenance Factor: .1
Handling Cost per Pound: 3.055
Management Cost per Pound: 1.130
Number of Workers Requiring Physical: 48
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: 0
Average Cost per Injury: 575
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 287
Number of Workers using PPE: 48
Dispensing and Tracking Factor: .86
Contractor Disposed Waste Liability Cost per Pound: 8.058
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .023
Support Equipment Cost per Pound: .031
Number of Workers Requiring Training: 48
Training Cost per Worker: 80.00
Transportation Cost per Pound: 1.466
Chemical Name: Trichloroethane
Substance ID Number: 006640387
Quantity Used: 1.9
Unit Of Issue: Gallons

Unit Cost: 15.02
Air / Environmental Contractor Disposal Percent: 73%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 15%
DRMO Cost per Pound: 1.072
DRMO Factor: 1
IWTP Percent: 2%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 10%
PPE Eye (Futura Goggles) Cost: 8.79
PPE Eye (Futura Goggles) Usage: 1
PPE Eye (Futura Goggles) Time Lost: 1%
PPE Eye (Futura Goggles) Time Worn: 100%
PPE Hand (Neoprene Gloves) Cost: 4.07
PPE Hand (Neoprene Gloves) Usage: 12
PPE Hand (Neoprene Gloves) Time Lost: 9%
PPE Hand (Neoprene Gloves) Time Worn: 25%
Physical Exam Cost: 115.99
Physical Exam Duration: 1 hours

Results (Thousands of Dollars)

Disposal : .1
Emergency Response: 0
Facilities: .04
Handling: .14
Management: .05
Medical: .97
PPE: 10.67
Potential Liability: .06
Procurement: .08
Support Equipment: 0
Training: .48
Transportation: .07

Total Cost: 12.66

Chemical #4 w/ Modified Values:
Estimate Base Year: 1996
Input Base Year: 1996
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Year/Subsystem
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 8
Surface Area of Subsystem: 22371
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 8

Number of Workers in Process: 48
Average Hourly Wage: 40
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .889
Facility Maintenance Factor: .1
Handling Cost per Pound: 3.055
Management Cost per Pound: 1.130
Number of Workers Requiring Physical: 48
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: 0
Average Cost per Injury: 575
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 287
Number of Workers using PPE: 48
Dispensing and Tracking Factor: .2
Contractor Disposed Waste Liability Cost per Pound: 8.058
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .023
Support Equipment Cost per Pound: .031
Number of Workers Requiring Training: 48
Training Cost per Worker: 80.00
Transportation Cost per Pound: 1.466
Chemical Name: Trichloroethane
Substance ID Number: 006640387
Quantity Used: 1.9
Unit Of Issue: Gallons

Unit Cost: 15.02
Air / Environmental Contractor Disposal Percent: 73%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 15%
DRMO Cost per Pound: 1.072
DRMO Factor: 1
IWTP Percent: 2%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 10%
PPE Eye (Futura Goggles) Cost: 8.79
PPE Eye (Futura Goggles) Usage: 1
PPE Eye (Futura Goggles) Time Lost: 0%
PPE Eye (Futura Goggles) Time Worn: 100%
PPE Hand (Neoprene Gloves) Cost: 4.07
PPE Hand (Neoprene Gloves) Usage: 12
PPE Hand (Neoprene Gloves) Time Lost: 0%
PPE Hand (Neoprene Gloves) Time Worn: 25%
Physical Exam Cost: 115.99
Physical Exam Duration: 1 hours

Results (Thousands of Dollars)

Disposal : .1
Emergency Response: 0
Facilities: .04
Handling: .14
Management: .05
Medical: .97
PPE: 2.12
Potential Liability: .06
Procurement: .08
Support Equipment: 0
Training: .48
Transportation: .07

Total Cost: 4.11

Chemical #5:
Estimate Base Year: 1996
Input Base Year: 1996
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Year/Subsystem
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 8
Surface Area of Subsystem: 22371
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 8

Number of Workers in Process: 8
Average Hourly Wage: 40
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .889
Facility Maintenance Factor: .1
Handling Cost per Pound: 3.055
Management Cost per Pound: 1.130
Number of Workers Requiring Physical: 8
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: 0
Average Cost per Injury: 575
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 287
Number of Workers using PPE: 8
Dispensing and Tracking Factor: .86
Contractor Disposed Waste Liability Cost per Pound: 8.058
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .023
Support Equipment Cost per Pound: .031
Number of Workers Requiring Training: 8
Training Cost per Worker: 80.00
Transportation Cost per Pound: 1.466
Chemical Name: Freezing Compound
Substance ID Number: 004059385
Quantity Used: 8
Unit Of Issue: 12 oz

Unit Cost: 4.02
Air / Environmental Contractor Disposal Percent: 15%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 45%
DRMO Cost per Pound: .343
DRMO Factor: 1
IWTP Percent: 2%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 40%
PPE Eye (Futura Goggles) Cost: 9.42
PPE Eye (Futura Goggles) Usage: 1
PPE Eye (Futura Goggles) Time Lost: 1%
PPE Eye (Futura Goggles) Time Worn: 100%
PPE Hand (Neoprene Gloves) Cost: 4.37
PPE Hand (Neoprene Gloves) Usage: 12
PPE Hand (Neoprene Gloves) Time Lost: 9%
PPE Hand (Neoprene Gloves) Time Worn: 25%
Physical Exam Cost: 115.99
Physical Exam Duration: 1 hours

Results (Thousands of Dollars)

Disposal : 0
Emergency Response: 0
Facilities: .02
Handling: .05
Management: .02
Medical: .19
PPE: 11.71
Potential Liability: .07
Procurement: .10
Support Equipment: 0
Training: .08
Transportation: .03

Total Cost: 12.26

Chemical #5 w/ Modified Values:
Estimate Base Year: 1996
Input Base Year: 1996
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Year/Subsystem
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 8
Surface Area of Subsystem: 22371
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 8

Number of Workers in Process: 8
Average Hourly Wage: 40
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .889
Facility Maintenance Factor: .1
Handling Cost per Pound: 3.055
Management Cost per Pound: 1.130
Number of Workers Requiring Physical: 8
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: 0
Average Cost per Injury: 575
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 287
Number of Workers using PPE: 8
Dispensing and Tracking Factor: .2
Contractor Disposed Waste Liability Cost per Pound: 8.058
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .023
Support Equipment Cost per Pound: .031
Number of Workers Requiring Training: 8
Training Cost per Worker: 80.00
Transportation Cost per Pound: 1.466
Chemical Name: Freezing Compound
Substance ID Number: 004059385
Quantity Used: 8
Unit Of Issue: 12 oz

Unit Cost: 4.02
Air / Environmental Contractor Disposal Percent: 15%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 45%
DRMO Cost per Pound: .343
DRMO Factor: 1
IWTP Percent: 2%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 40%
PPE Eye (Futura Goggles) Cost: 9.42
PPE Eye (Futura Goggles) Usage: 1
PPE Eye (Futura Goggles) Time Lost: 0%
PPE Eye (Futura Goggles) Time Worn: 100%
PPE Hand (Neoprene Gloves) Cost: 4.37
PPE Hand (Neoprene Gloves) Usage: 12
PPE Hand (Neoprene Gloves) Time Lost: 0%
PPE Hand (Neoprene Gloves) Time Worn: 25%
Physical Exam Cost: 115.99
Physical Exam Duration: 1 hours

Results (Thousands of Dollars)

Disposal : 0
Emergency Response: 0
Facilities: .02
Handling: .05
Management: .02
Medical: .19
PPE: 2.14
Potential Liability: .07
Procurement: .10
Support Equipment: 0
Training: .08
Transportation: .03

Total Cost: 2.70

Chemical #6:
Estimate Base Year: 1996
Input Base Year: 1996
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Year/Subsystem
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 8
Surface Area of Subsystem: 22371
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 8

Number of Workers in Process: 6775
Average Hourly Wage: 40
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .889
Facility Maintenance Factor: .1
Handling Cost per Pound: 3.055
Management Cost per Pound: 1.130
Number of Workers Requiring Physical: 6775
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: 0
Average Cost per Injury: 575
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 287
Number of Workers using PPE: 8
Dispensing and Tracking Factor: .86
Contractor Disposed Waste Liability Cost per Pound: 8.058
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .023
Support Equipment Cost per Pound: .031
Number of Workers Requiring Training: 6775
Training Cost per Worker: 80.00
Transportation Cost per Pound: 1.466
Chemical Name: Sealing Compound
Substance ID Number: 000087198
Quantity Used: 1250
Unit Of Issue: kit

Unit Cost: 19.83
Air / Environmental Contractor Disposal Percent: 2%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 5%
DRMO Cost per Pound: 2.294
DRMO Factor: 1
IWTP Percent: 2%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 93%
PPE Eye (Wilson Spectra Safety Glasses) Cost: 7.93
PPE Eye (Wilson Spectra Safety Glasses) Usage: 1
PPE Eye (Wilson Spectra Safety Glasses) Time Lost: 1%
PPE Eye (Wilson Spectra Safety Glasses) Time Worn: 100%
PPE Hand (Neoprene Gloves) Cost: 4.07
PPE Hand (Neoprene Gloves) Usage: 12
PPE Hand (Neoprene Gloves) Time Lost: 9%
PPE Hand (Neoprene Gloves) Time Worn: 25%
Physical Exam Cost: 115.99
Physical Exam Duration: 1 hours

Results (Thousands of Dollars)

Disposal : .85
Emergency Response: 0
Facilities: 7.2
Handling: 22.51
Management: 8.33
Medical: 141.94
PPE: 2347.01
Potential Liability: 3.37
Procurement: 73.07
Support Equipment: .23
Training: 67.75
Transportation: 10.81

Total Cost: 2683.07

Chemical #6 w/ Modified Values:
Estimate Base Year: 1996
Input Base Year: 1996
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Year/Subsystem
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 8
Surface Area of Subsystem: 22371
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 8

Number of Workers in Process: 6775
Average Hourly Wage: 40
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .889
Facility Maintenance Factor: .1
Handling Cost per Pound: 3.055
Management Cost per Pound: 1.130
Number of Workers Requiring Physical: 6775
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: 0
Average Cost per Injury: 575
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 287
Number of Workers using PPE: 8
Dispensing and Tracking Factor: .2
Contractor Disposed Waste Liability Cost per Pound: 8.058
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .023
Support Equipment Cost per Pound: .031
Number of Workers Requiring Training: 6775
Training Cost per Worker: 80.00
Transportation Cost per Pound: 1.466
Chemical Name: Sealing Compound
Substance ID Number: 000087198
Quantity Used: 1250
Unit Of Issue: kit

Unit Cost: 19.83
Air / Environmental Contractor Disposal Percent: 2%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 5%
DRMO Cost per Pound: 2.294
DRMO Factor: 1
IWTP Percent: 2%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 93%
PPE Eye (Wilson Spectra Safety Glasses) Cost: 7.93
PPE Eye (Wilson Spectra Safety Glasses) Usage: 1
PPE Eye (Wilson Spectra Safety Glasses) Time Lost: 2%
PPE Eye (Wilson Spectra Safety Glasses) Time Worn: 100%
PPE Hand (Neoprene Gloves) Cost: 4.07
PPE Hand (Neoprene Gloves) Usage: 12
PPE Hand (Neoprene Gloves) Time Lost: 2%
PPE Hand (Neoprene Gloves) Time Worn: 25%
Physical Exam Cost: 115.99
Physical Exam Duration: 1 hours

Results (Thousands of Dollars)

Disposal : .85
Emergency Response: 0
Facilities: 7.2
Handling: 22.51
Management: 8.33
Medical: 141.94
PPE: 1811.7
Potential Liability: 3.37
Procurement: 73.07
Support Equipment: .23
Training: 67.75
Transportation: 10.81

Total Cost: 2147.76

Chemical #7:
Estimate Base Year: 1996
Input Base Year: 1996
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Year/Subsystem
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 8
Surface Area of Subsystem: 22371
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 8

Number of Workers in Process: 1
Average Hourly Wage: 40
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .889
Facility Maintenance Factor: .1
Handling Cost per Pound: 3.055
Management Cost per Pound: 1.130
Number of Workers Requiring Physical: 1
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: 0
Average Cost per Injury: 575
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 287
Number of Workers using PPE: 8
Dispensing and Tracking Factor: .86
Contractor Disposed Waste Liability Cost per Pound: 8.058
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .023
Support Equipment Cost per Pound: .031
Number of Workers Requiring Training: 1
Training Cost per Worker: 80.00
Transportation Cost per Pound: 1.466
Chemical Name: Trichlorotrifluorethane
Substance ID Number: 005842957
Quantity Used: 9.4
Unit Of Issue: Pounds

Unit Cost: 3.7
Air / Environmental Contractor Disposal Percent: 73%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 15%
DRMO Cost per Pound: 1.147
DRMO Factor: 1
IWTP Percent: 2%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 10%
PPE Eye (Splash Guard Chem Goggles) Cost: 9.37
PPE Eye (Splash Guard Chem Goggles) Usage: 1
PPE Eye (Splash Guard Chem Goggles) Time Lost: 1%
PPE Eye (Splash Guard Chem Goggles) Time Worn: 100%
PPE Hand (PCB Resistant Gloves) Cost: 9.94
PPE Hand (PCB Resistant Gloves) Usage: 12
PPE Hand (PCB Resistant Gloves) Time Lost: 9%
PPE Hand (PCB Resistant Gloves) Time Worn: 25%
Physical Exam Cost: 115.99
Physical Exam Duration: 1 hours

Results (Thousands of Dollars)

Disposal : .01
Emergency Response: 0
Facilities: .03
Handling: .08
Management: .03
Medical: .06
PPE: 9.30
Potential Liability: .04
Procurement: .1
Support Equipment: 0
Training: .01
Transportation: .04

Total Cost: 9.70

Chemical #7 w/ Modified Values:
Estimate Base Year: 1996
Input Base Year: 1996
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Year/Subsystem
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 8
Surface Area of Subsystem: 22371
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 8

Number of Workers in Process: 1
Average Hourly Wage: 40
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .889
Facility Maintenance Factor: .1
Handling Cost per Pound: 3.055
Management Cost per Pound: 1.130
Number of Workers Requiring Physical: 1
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: 0
Average Cost per Injury: 575
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 287
Number of Workers using PPE: 8
Dispensing and Tracking Factor: .2
Contractor Disposed Waste Liability Cost per Pound: 8.058
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .023
Support Equipment Cost per Pound: .031
Number of Workers Requiring Training: 1
Training Cost per Worker: 80.00
Transportation Cost per Pound: 1.466
Chemical Name: Trichlorotrifluorethane
Substance ID Number: 005842957
Quantity Used: 9.4
Unit Of Issue: Pounds

Unit Cost: 3.7
Air / Environmental Contractor Disposal Percent: 73%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 15%
DRMO Cost per Pound: 1.147
DRMO Factor: 1
IWTP Percent: 2%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 10%
PPE Eye (Splash Guard Chem Goggles) Cost: 9.37
PPE Eye (Splash Guard Chem Goggles) Usage: 1
PPE Eye (Splash Guard Chem Goggles) Time Lost: 0%
PPE Eye (Splash Guard Chem Goggles) Time Worn: 100%
PPE Hand (PCB Resistant Gloves) Cost: 9.94
PPE Hand (PCB Resistant Gloves) Usage: 12
PPE Hand (PCB Resistant Gloves) Time Lost: 0%
PPE Hand (PCB Resistant Gloves) Time Worn: 25%
Physical Exam Cost: 115.99
Physical Exam Duration: 1 hours

Results (Thousands of Dollars)

Disposal : .01
Emergency Response: 0
Facilities: .03
Handling: .08
Management: .03
Medical: .06
PPE: 2.10
Potential Liability: .04
Procurement: .1
Support Equipment: 0
Training: .01
Transportation: .04

Total Cost: 2.50

Chemical #8:
Estimate Base Year: 1996
Input Base Year: 1996
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Year/Subsystem
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 8
Surface Area of Subsystem: 22371
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 8

Number of Workers in Process: 20
Average Hourly Wage: 40
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .889
Facility Maintenance Factor: .1
Handling Cost per Pound: 3.055
Management Cost per Pound: 1.130
Number of Workers Requiring Physical: 20
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: 0
Average Cost per Injury: 575
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 287
Number of Workers using PPE: 8
Dispensing and Tracking Factor: .86
Contractor Disposed Waste Liability Cost per Pound: 8.058
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .023
Support Equipment Cost per Pound: .031
Number of Workers Requiring Training: 20
Training Cost per Worker: 80.00
Transportation Cost per Pound: 1.466
Chemical Name: Sealing Compound Primer
Substance ID Number: 001818372
Quantity Used: .4
Unit Of Issue: 6 oz

Unit Cost: 2.67
Air / Environmental Contractor Disposal Percent: 2%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 5%
DRMO Cost per Pound: 2.294
DRMO Factor: 1
IWTP Percent: 2%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 93%
PPE Eye (Futura Goggles) Cost: 9.42
PPE Eye (Futura Goggles) Usage: 1
PPE Eye (Futura Goggles) Time Lost: 1%
PPE Eye (Futura Goggles) Time Worn: 100%
PPE Hand (Neoprene Gloves) Cost: 4.37
PPE Hand (Neoprene Gloves) Usage: 12
PPE Hand (Neoprene Gloves) Time Lost: 9%
PPE Hand (Neoprene Gloves) Time Worn: 25%
Physical Exam Cost: 115.99
Physical Exam Duration: 1 hours

Results (Thousands of Dollars)

Disposal : 0
Emergency Response: 0
Facilities: 0
Handling: 0
Management: 0
Medical: .43
PPE: 15.86
Potential Liability: 0
Procurement: 0
Support Equipment: 0
Training: .2
Transportation: 0

Total Cost: 16.49

Chemical #8 w/ Modified Values:
Estimate Base Year: 1996
Input Base Year: 1996
Discount Rate: 10%
Inflation Table: User
Number of Hours per Year: 2080
Type of Analysis: Year/Subsystem
System Name: Aircraft
System Type: Cargo
Subsystem Name: Airframe
Number of Subsystems per Year: 8
Surface Area of Subsystem: 22371
Composite Surface Area: 0
Titanium Surface Area: 0
Phase Name: Acquisition
Number of Systems Acquired: 8

Number of Workers in Process: 20
Average Hourly Wage: 40
Disposal Contractor Analysis/ Classification Cost per Pound: .002
Emergency Response Cost per Pound: 0
Facility Cost per Pound: .889
Facility Maintenance Factor: .1
Handling Cost per Pound: 3.055
Management Cost per Pound: 1.130
Number of Workers Requiring Physical: 20
Medical Surveillance Cost per Worker: 0
Average Number of Injuries per Worker: 0
Average Cost per Injury: 575
Number of Industrial Hygiene Surveys per Year: 1
Cost per Industrial Hygiene Survey: 287
Number of Workers using PPE: 8
Dispensing and Tracking Factor: .2
Contractor Disposed Waste Liability Cost per Pound: 8.058
Ground Water Contamination Chance Percent: 1%
Hazardous Air Emissions Liability Cost per Pound: .023
Support Equipment Cost per Pound: .031
Number of Workers Requiring Training: 20
Training Cost per Worker: 80.00
Transportation Cost per Pound: 1.466
Chemical Name: Sealing Compound Primer
Substance ID Number: 001818372
Quantity Used: .4
Unit Of Issue: 6 oz

Unit Cost: 2.67
Air / Environmental Contractor Disposal Percent: 2%
Air / Environmental Contractor Disposal Cost Per Pound: 0
Air / Environmental Contractor Disposal Factor: 1
DRMO Percent: 5%
DRMO Cost per Pound: 2.294
DRMO Factor: 1
IWTP Percent: 2%
IWTP Cost per Pound: .001
IWTP Factor: 10,000
Recycle Percent: 0%
Recycle Cost per Pound: 0
Recycle Factor: 1
In Process: 93%
PPE Eye (Futura Goggles) Cost: 9.42
PPE Eye (Futura Goggles) Usage: 1
PPE Eye (Futura Goggles) Time Lost: 1%
PPE Eye (Futura Goggles) Time Worn: 100%
PPE Hand (Neoprene Gloves) Cost: 4.37
PPE Hand (Neoprene Gloves) Usage: 12
PPE Hand (Neoprene Gloves) Time Lost: 9%
PPE Hand (Neoprene Gloves) Time Worn: 25%
Physical Exam Cost: 115.99
Physical Exam Duration: 1 hours

Results (Thousands of Dollars)

Disposal : 0
Emergency Response: 0
Facilities: 0
Handling: 0
Management: 0
Medical: .43
PPE: 2.23
Potential Liability: 0
Procurement: 0
Support Equipment: 0
Training: .2
Transportation: 0

Total Cost: 2.86

Bibliography

Aerospace Industries Association. National Aerospace Standard (NAS) 411. Hazardous Materials Management Program. Washington D.C. 1993.

Air Force Material Command. Acquisition Pollution Prevention AFMC Implementation Guide. Volume II, Wright Patterson AFB, OH. 1992.

Balci, Osman. "Validation, Verification, and Testing Techniques Throughout the Life Cycle of a Simulation Study," Virginia Polytehnic Institute. 1994. p. 121-172.

Banks, Jerry. "Modeling processes, validation, and derification of complex simulations: A survey. Methodology and Validation. Volume 19. 1987.

Blanchard, B. Design and Manage to Life Cycle Cost, Englewood Cliffs, New Jersey Prentice Hall 1995.

Blanchard, B. System Engineering Management. Portland, Oregon. M/A Press. 1978.

Brown, Linda. "Life-cycle assessment in practice," Pollution Prevention Review, Autumn, 1995.

Clemen, Robert T. Making Hard Decisions: An Introduction to Decision Analysis. Belmont, California. Duxbury Press. 1991.

Communications Training Analysis Corporation. "Evaluation of Environmental Management Cost-Estimating Capabilities for Major Defense Acquisition Programs" 22 March 1995.

Department of Defense Direction 4210.15. Hazardous Material Pollution Prevention. Washington D.C. 27 July 1989

Department of Defense Instruction 5000.2. System Safety, Health Hazards and Environmental Impact. Washington D.C. 23 Mar 1995

Department of Defense Regulation 5000.2R. 15 Mar 1996.

Devore, Jay. Probability and Statistics for Engineering and the Sciences. New York. Duxbury Press. 1995.

Dorfman, Mark. "Source Reduction: Environmental Dividends from Cutting Chemical Waste," Pollution Prevention Review. Autumn, 1992. p.406-409.

Fabrycky, W. Life-Cycle Cost and Economic Analysis . Englewood Cliffs, New Jersey Prentice Hall, 1991.

Fossett, C, Gass, S, Harrison, D, and Weintrob, H. "An assessment procedure for simulation models," Operations Research, Vol.39, 1991. p.711-723.

Gass, Saul. "Guidelines for Model Evaluation: Abridged Version of the U.S. General Accounting Office Exposure Draft," Operations Research, Vol 28, No.2, 1980.

Hatcher, Larry. A Step-by-Step Approach to Using the SAS System for Univariate and Multivariate Statistics. SAS Institute Inc. 1994.

Keoleian, G, Menerey, D, and Curran, M. "A Life Cycle Approach to Product Design," Pollution Prevention Review. Summer 1993.

Law, A and Kelton, W. Simulation Modeling and Analysis. New York, McGraw-Hill Book Company. 1982.

Long, John. Analyst for The Analytical Sciences Corporation (TASC). Personal Correspondence. 25 May 1996.

MITRE. Review and Analysis of Hazardous Material Life Cycle Cost Estimating Requirements. McLean, Virigina. January, 1995.

Reynolds, Dan. Professor in the Math Department, Air Force Institute of Technology Personal Correspondence. 25 Sep 1996.

Sargent, Robert K. "Validation and Verification of Simulation Models," 1994 Winter Simulation Conference, Syracuse, NY. 1992. p.77-87.

Secretary of the Air Force. Memorandum for ALMAJCOM/CC, "Air Force Pollution Prevention Strategy," 24 Jul 1995.

Slusarz, Mark. Life Cycle Cost Analyst for McDonnell Douglas Aircraft. Personal Correspondence and Interview. 25 May 1996.

The Analytical Sciences Corporation. Hazardous Material Cost Trade-Off User's Guide. 20 March 1996.

West, Betty. Program Manager for Brooks Air Force Base. Telephone Conversation 3 Oct 1996.

Vita

Captain Thomas Choi was born 18 June 1969 in Seoul, South Korea. He graduated from John A Rowland High School in 1987 and attended the United States Air Force Academy in Colorado Springs, Colorado. He graduated on 29 May 1991 with a Bachelor of Science degree in Civil Engineering and was commissioned that same day. His first assignment was to the 22nd Civil Engineering Squadron at March Air Force Base in Riverside, California as a civil engineer. He also served as the Deputy Chief of Contract Management, Chief of Maintenance Engineering, and Chief of Compliance in the Environmental Flight. He entered the School of Engineering, Air Force Institute of Technology in May 1995. His next assignment is to Yokota Air Base, Japan. He is married to Susan Ku and currently has no children.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 1996	Master's Thesis

4. TITLE AND SUBTITLE

Independent Verification and Validation of the HAZMAT CTAT Developed by the Human Systems Center at Brooks AFB

5. FUNDING NUMBERS

6. AUTHOR(S)

Thomas S. Choi, Capt, USAF

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Air Force Institute of Technology (AFIT)
Wright Patterson AFB, OH 45433-6583

8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT/GEE/ENV/96D

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Bertty West
HSC/EMP
8213 14th St
Brooks AFB, TX. 78235-5246

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Air Force realizes that the life cycle cost (LCC) associated with hazardous materials is a significant cost in the acquisition of major weapon systems. In trying to mitigate the growth of environmental LCC for future weapon systems, the Air Force has developed a tool called the Hazardous Material Cost Trade-off Analysis Tool (HAZMAT CTAT). The HAZMAT CTAT estimates the LCC for weapon system hazardous materials, so that intelligent decisions can be made in the early stages of the acquisition process. The problem with implementing this program into the acquisition process is that an independent computer model evaluation has never been conducted on the HAZMAT CTAT program. This thesis contains a rigorous computer model evaluation of the HAZMAT CTAT. The evaluation includes a computer model verification study using Decision Program Language (DPL) to verify if the HAZMAT CTAT model and an operational validation study using C-17 historical data to test if the HAZMAT CTAT accurately predicts actual costs.

14. SUBJECT TERMS

verification, validation, hazardous materials, environment, environmental, life cycle costing, weapon systems, acquisition, computer model evaluation, sensitivity analysis

15. NUMBER OF PAGES

202

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL